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6 MULTIPATH INTERFERENCE PREDICTION STUDY FOR DABOB BAY AND NANOOSE BAY SONAR CHANNELS,

Prepared under Singer-Librascope
IR&D Program I7-731-DA

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1.0 INTRODUCTION

The purpose of this study is to determine the feasibility to communicate tracking data by UQC underwater telephone to submarines operating within the 3-D tracking areas in Dabob Bay and Nanoose Bay. The ability to communicate reliably and at a sufficient data rate depends upon three factors. The first factor is the ability to reliably transmit sound from a source to a receiver. Assuming that the power level of the transmitter is sufficient to produce an acceptable signal to noise ratio at the receiver, the ability to transmit sound from one point to another depends mainly upon the prevailing velocity profile and geometrical characteristics of the sonar channel. The second factor is the arrival time difference between a direct ray and other rays traveling paths different from the path of the direct ray. This arrival time difference termed the "clear time window" throughout this report, represents the length of a message that can be received without interference. Influencing the magnitude of the clear time windows are the position of the receiver relative to the source, the velocity profile, bottom and surface loss, bottom depth and geometrical characteristics of the sonar channel. The third factor is the maximum possible data rate. The data rate is determined by the available bandwidth, clear time windows and total reverberation decay time.

This study is therefore concerned with the influence of the Dabob Bay and Nanoose Bay sonar channels on the coverage radius of the UQC projectors, on the multipath interference patterns which determine clear time windows and on reverberation decay time.

Based upon data concerning the physical characteristics of Dabob Bay and Nanoose Bay, the following topics are discussed:

<u>Characteristics of the Dabob Bay Sonar Channel</u>

In this section, the tracking area, channel depth, bottom and surface loss coefficients and velocity profiles are discussed.

Results of Curvilinear Ray Trace Programs for Dabob Bay

The velocity profiles are analyzed by curvilinear ray trace programs to determine:

a. Effective coverage radius of UQC projectors

b. Limitations on beam patterns of projectors and receiver hydrophones

c. Clear time windows

d. Reverberation decay time

e. Maximum data transmission rate

Characteristics of the Nanoose Bay Sonar Channel

In this section, the tracking area, channel depth, bottom and surface loss coefficients and velocity profiles are discussed.

Analysis of Nanoose Bay Velocity Profiles

This section deals with the effective coverage radius of UQC projectors based upon a statistical analysis of velocity profiles.

Results of Curvilinear Ray Trace Programs for Nanoose Bay

A velocity profile is analyzed by curvilinear ray trace programs to determine:

a. Limitations of beam patterns of projectors and hydrophones

b. Clear time windows

c. Reverberation decay time

d. Maximum data transmission rate

2.0 SUMMARY

Data consisting of velocity profiles, bottom loss coefficients, and charts of Dabob Bay and Nanoose Bay was analyzed to determine the feasibility of communicating by UQC to submarines operating in the 3-D tracking areas of both bays. The approach consisted of using curvilinear ray trace programs and statistical analysis to analyze the velocity profiles and determine effective radius of coverage for the UQC projectors and clear time window zones.

From the analysis of four of the seven velocity profiles of Dabob Bay by a curvilinear ray trace program, it was determined that restrictions must be imposed on the beam patterns of the UQC projectors and receive hydrophones. The restriction is necessary to avoid multipath interference zones where the arrival time difference between the direct ray and interfering ray is less than 7 msec. The restriction consists of limiting the beam pattern of the UQC projectors to a hemisphere looking upward and the beam pattern of the receive hydrophones to a hemisphere looking downward.

Further analysis has shown that with these beam pattern restrictions, clear time windows in excess of 40 msec exist out to a range of 1700 yards from a UQC projector located in Dabob Bay. However, because of these beam pattern restrictions the effective radius of coverage per projector at the maximum operating depth of 100 yards was found to be 1250 yards to 1750 yards depending upon the depth and location of the projector. Because of the limited radius of coverage, four or five projectors are needed in Dabob Bay to effectively cover the 3-D tracking area.

Because of the similarity between the nine profiles obtained from Nanoose Bay, only one profile was analyzed to determine the clear time window zones. It was found that clear time windows in excess of 100 msec exist out to a range of 2800 yards from a UQC projector located in Nanoose Bay. In order to obtain this clear time window, it is necessary to impose the same restrictions as in Dabob Bay on the beam patterns of the projectors and hydrophones.

The velocity profiles for Nanoose Bay show an almost constant positive gradient from 600 feet to the 1320 foot bottom. It was therefore possible to calculate without using a ray trace program, the effective coverage radius per projector. At the maximum operating depth of 1000 feet in Nanoose Bay, the effective coverage radius per projector was found to be 2600 yards. This figure is based upon a statistical analysis of the nine profiles and represents a 98% confidence level. Since the analysis was based upon velocity profile samples representing all seasons of the year, it is expected that a maximum radius of coverage of 2600 yards is a good estimate for all times of the year. With a 2600 yard radius of coverage per projector, five projectors are needed to effectively cover the 3-D tracking area in Nanoose Bay.

Factors determining the rate at which data can be transmitted through a sonar channel are message length, and message repetition rate. Because of the UQC 2800 Hz bandwidth, a bit length of 1 msec is possible in a FSK system. With a clear time window of 40 msec in Dabob Bay and 100 msec in Nanoose Bay, message lengths of 40 bits and 100 bits are possible in Dabob Bay and Nanoose Bay, respectively. The factor which determines message repetition rate is the reverberation decay time in the sonar channel. This time could not be calculated due to limitations in the ray trace programs and available data. An assumption of 600 msec for reverberation decay time in Dabob Bay and one second for reverberation decay time in Nanoose Bay is made for analytical purposes only.

Based upon the clear time windows determined by analysis and upon the assumed reverberation decay times, a data rate of 67 bits per second is feasible in Dabob Bay and 100 bits per second is feasible in Nanoose Bay.

3.0 DABOB BAY

3.1 CHARACTERISTICS OF THE DABOB BAY SONAR CHANNEL

Figure 1 is a chart of the 3-D tracking range in Dabob Bay. The tracking area, formed by five hydrophones spaced 2000 yards apart on a line 200 yards east of the range center line, is approximately a rectangle 2600 yards wide and 10,500 yards long. The depth within the tracking area is shallow, ranging from 30 yards along the perimeter to 200 yards in the center of the tracking area. Submarines in the tracking area during test operations run at keel depths of 20 yards minimum (periscope depth) to 100 yards maximum. The communications system must maintain reliable communications with a submarine operating any where within the tracking area at normal depths. Communication projectors will be placed on or near the bottom so that their mounting structures are not a hazard to submarines. The number and placement of projectors to effectively cover the required volume of water will be discussed in the following section of this report.

Because of the shallow channel depth, most of the multipath interference will be due to bottom and surface reflections. The relative intensity between the reflected rays and direct rays depend upon the loss coefficients of the bottom and surface and the difference in path lengths. Bottom loss data for Dabob Bay is shown in Table 1. Based upon the data shown in Table 1, a bottom loss coefficient of 2 db was selected as representative for Dabob Bay for all ray trace analysis. This coefficient was selected since it represents the bottom loss at a grazing angle of 15 degrees to 20 degrees. Surface-bottom reflected rays at a 15 degree grazing angle intersect direct rays at a range of 1700 yards to 2600 yards. It will be shown in the next section that the maximum radius of coverage of a UQC projector is around 1700 yards. Since the bottom loss increases with grazing angle, the bottom loss coefficient of 15 degrees grazing angle represents worst case out to ranges of 1700 yards. No surface loss data was available for Dabob Bay. However, surface reflection losses are dependent upon the frequency and grazing angle of the reflected wave and the sea surface roughness. Tests conducted by R. H. Adlington (Reference 1) indicate that there is no loss of energy at a reflection at the sea surface over grazing angles of 10 to 55 degrees in the frequency range 400 to 6400 Hz. Other tests conducted by Urick and Saxon (Reference 2) have shown an average surface reflection loss of 3 db at grazing angles between 3 and 18 degrees at a frequency of 25 KHz. Since the UQC carrier frequency is in the range 8 to 11 KHz, a surface loss coefficient of 1 db was selected for all ray trace analysis.

Seven velocity profiles of Dabob Bay were obtained by a Digital Oceanographic Data Acquisition System (DODAS) which measures velocity to an accuracy of ±1.65 feet per second. The velocity profiles are shown in Figures 2 through 8. Each season of the year is represented at least once. The profiles vary too much in shape to allow any predictions as to standard shape or worst case shape limits. For this reason, it is necessary to run a ray trace analysis for each profile in order to determine sonar coverage and clear time window contours.

3.2 RESULTS OF CURVILINEAR RAY TRACES FOR DABOB BAY

Before any ray trace analysis was done, the measured velocity profiles were converted to continuous gradient velocity profiles by means of a Continuous Gradient Sound Velocity Curve Fitting Routine developed by M. E. Scharer of Librascope (Reference 3). Ray traces were then performed for the fitted velocity profiles by means of three ray trace programs. The first program is the Curvilinear Profile Ray Trace Program developed by M. E. Scharer (Reference 4) which traces a ray from an initial point and an initial depression angle, to a depth and range where the propagation loss reaches a preassigned level. The second program is a modification of the first and traces a ray to a point where it changes direction in the vertical direction. This program is useful in obtaining coverage of direct rays going in one direction. The third program is also a modification of the first and prints out the intersection points of two or more rays. Since the transit time and propagation loss of each ray is computed by the program, the arrival time difference and relative intensity between the rays at an intersection point can be computed to obtain clear time windows and relative intensity contours.

The results of Ray Trace Program #1 are shown in Figures 9 through 12 and indicate the multipath interference problem between direct and refracted rays, between two refracted rays, and between bottom reflected rays and direct rays. For example, in Figure 9, the arrival time difference between the -5° refracted ray and the +1.5° direct ray, is 5 milliseconds. Figure 10 shows an arrival time difference between the -6° refracted ray and -4° direct ray of 1 millisecond and an arrival time difference between the -3° and -2° refracted rays of 7 milliseconds. Figure 11 shows an arrival time difference of 1 millisecond between the -8° and -7° refracted rays. Figure 9 also shows an arrival time difference of 1 millisecond between the +2° bottom reflected ray and the -1° direct ray. Time differences this small create time dispersion of a communications signal and cause garbling of the message. Therefore, restrictions on the beam patterns of both projectors and receiving hydrophones are necessary to avoid these short time difference interference zones. First, the receive hydrophones on the submarines must have a beam pattern that receives only upward traveling rays. Second, the beam pattern of the bottom mounted projectors must be such that bottom reflected rays do not intersect any direct upward going rays. With these restrictions placed upon the beam patterns, the main source of multipath interference will be a surface-bottom reflected ray with a direct ray. Another source of multipath interference is reflection from the walls of the Bay. However, since the transit time of rays reflected from the Bay walls is much longer than the transit time of a surface-bottom reflected ray, the Bay wall reflected rays will not determine clear window times. Instead, they will be counted in the reverberation decay times.

Ray Trace Program #3 was used to compute the arrival time differences of direct rays and surface-bottom reflected rays (clear time window) for six of the seven profiles with the projector located four yards from the bottom. For lack of better data the bottom was assumed to be flat. The results are shown in Figures 13 through 19. Figure 20 shows the overall clear time window contours for the seven profiles. Since the clear time window decreases with increasing receiver depth, the maximum operating depth will represent the smallest clear time window. Thus at a depth of 100 yards, a clear time window of 30 msec or greater can be expected out to ranges of 2150 yards, 40 msec or greater out to 1700 yards. Also shown in Figure 20 is a 4 db contour. At ranges greater than the contour the relative attenuation is less than 4 db. This contour represents the relative strength between the direct ray and surface-bottom reflected rays and shows that the strength of the interfering ray is sufficient to garble a message if the message is longer than the clear time window. A signal to interference ratio of 15 db minimum is considered necessary to insure reliable reception of a message. However, clear time windows of these magnitudes will permit reliable communications of a suitable data rate. The bandwidth of the UQC system is 2800 Hz. With this bandwidth it is possible to use a FSK communications code with the two frequencies spaced 1600 Hz apart and a bit length of 1 msec. Thus, 40 bits can be transmitted in a 40 msec message. The message repetition rate depends upon the total reverberation decay time in the sonar channel which is not known exactly at the present time. The programs can trace rays reflected from a sloping bottom, however, total reverberation decay time depends upon reflections in three dimensions and cannot be handled by the existing programs. Assuming a reverberation decay time of 600 msec, a data rate of 67 bits per second is realizable in Dabob Bay. This assumption is made for analytical purposes only.

Because of the restrictions placed upon the projector and hydrophone beam patterns, direct ray coverage is the limiting factor in establishing the reliability of communications. Figures 13 through 19 show upward going direct ray coverage of depth versus range for profiles D-1 through D-7 with the projector located at a depth of 196 yards (196 yards was chosen because projectors are currently mounted four yards from the bottom). The smallest coverage is shown in Figure 18 (Profile D-6) where the 0°

ray crosses the 100 yard depth at 1750 yards range. Using 1750 yards as the radius of coverage per projector, and allowing for sufficient overlap to effectively cover the entire tracking area, four projectors are needed to effectively communicate in the tracking area.

The chart of Dabob Bay is incomplete in that no depth contours are shown between 120 yards and 200 yards. Thus it is highly probable that the projectors will be placed on a slope rather than at the maximum bottom depth of the channel. In this case the depth of the projectors will be less than 196 yards. Figures 21 through 27 show direct upward going ray coverage for the projectors located at a depth of 167 yards. The smallest coverage again is due to velocity profile D-6 shown in Figure 26. The zero degree ray crosses the 100 yard depth at a range of 1250 yards. With 1250 yards as the maximum radius of coverage per projector, five projectors are required to cover the tracking area.

4.0 NANOOSE BAY

4.1 CHARACTERISTICS OF NANOOSE BAY SONAR CHANNEL

Figure 28 is a chart of the Nanoose 3-D tracking range. The tracking area is shown formed by 11 hydrophones, each with an effective 1500 yard radius of coverage. The depth within the tracking area is 440 yards and nearly constant throughout the entire area except for the region covered by hydrophone -07. In this region there is a steep rise of 215 yards. Submarines operate within the tracking area during test operations at depths of 20 yards minimum to 333 yards maximum. The communications system must maintain reliable communications with a submarine operating anywhere with the tracking area at normal operating depths. Communication projectors, as in Dabob Bay, will be placed on or near the bottom so that their mounting structures are not a hazard to submarines.

Bottom loss data for Nanoose range is shown in Table 2. Based upon this a data, bottom loss coefficient of 13 db was selected for Nanoose for all ray trace analysis. This value was selected since it is worst case. As in Dabob Bay, a surface loss coefficient of 1 db was selected for Nanoose.

Nine velocity profiles of Nanoose range were obtained by DODAS and are shown in Figures 29 through 37. Each season of the year is represented at least once by the sample of velocity profiles. Profiles N-1 through N-8 are incomplete in that velocities are shown down to 800 feet rather than to the 1320 foot bottom. However, based upon the following observations, it is possible to project the velocity data to the bottom:

1. The salinity remains relatively constant below 500 feet for all eight profiles.
2. The temperature tends to either remain constant below 600 feet or has a slight positive gradient up to .003°C per foot.

3. Velocity profile N-9 which has complete velocity data to the bottom shows that the velocity gradient at the bottom is the same as that at 600 to 800 feet.

4. Nanoose range has no fresh water inlets which tend to cause unpredicable variations in temperature and salinity and thus velocity.

For profiles N-1 through N-8, velocity was determined to the bottom by projecting the gradient that exists at 600 to 800 feet. Because all nine profiles are similar in shape below a depth of 60 feet and have a constant gradient extending from 600 to 1320 feet, it is possible to predict, analytically, sonar coverage in Nanoose range.

4.2 ANALYSIS OF NANOOSE BAY VELOCITY PROFILES

Appendix A shows the approach used to predict sonar coverage based upon a sample of velocity profiles. In this approach, a statistical analysis was performed to determine the distribution function and density function for the velocity gradient based upon the nine samples. Using the ray refraction equations for a constant gradient outlined in Officer (Reference 5), it was possible to determine coverage contours for Nanoose for projectors located four yards from the bottom. Figure 38 shows the distribution functions for the zero degree ray crossing the depths of 333 yards and 200 yards. Figure 39 shows contours of various confidence levels based upon the distribution function. Receivers at a depth of 333 yards (maximum operating depth) can expect direct ray coverage with a 98% confidence level out to a range of 2600 yards. Coverage at depths less than 333 yards up to 20 yards can be expected with a confidence level greater than 98%. Most of the profiles show a large negative velocity gradient down to about 20 yards. This gradient results in a sharp refraction of rays downward, creating a shadow zone near the surface. However, since the minimum operating depth of the submarine is 20 yards, the reliability of communications should not suffer due to this gradient.

4.3 RESULTS OF RAY TRACE ANALYSIS FOR NANOOSE BAY

Because of the similarity of all profiles, it was necessary to perform a ray trace analysis on only one profile to obtain clear time window contours. Figure 40 shows the clear time window contours obtained for profile N-4. At a depth of 333 yards, a clear time window of greater than 120 msec can be expected out to 2200 yards, and greater than 100 msec out to 2800 yards. These clear time window contours were calculated as in Dabob Bay, that is, the arrival time difference between a surface-bottom reflected ray and a direct ray. As in the case of Dabob Bay, the multipath interference resulting from refracted ray to refracted ray, refracted ray to direct ray and bottom reflected ray to direct ray are to be avoided because of the short arrival time differences. Thus the same restrictions must be imposed on the beam patterns of the projectors and receiving hydrophones, that is, a hemispherical downward pattern for the hydrophones, and a hemispherical upward pattern for the projectors. Based upon a clear time window of 100 msec and a bit length of 1 msec, 100 bits per message is possible. The message rate as in Dabob Bay will depend upon the total reverberation decay time in the sonar channel. The time is unknown at present but for analytical purposes is assumed to be around one second. With the assumption of a one second reverberation time, a data rate of 100 bits per second is possible in Nanoose Bay.

Figure 40 also shows a 15 db contour. This contour represents the relative intensity between the direct ray and surface-bottom reflected rays. For ranges greater than the contour, the relative intensity is less than 15 db. This contour shows that the strength of an interfering ray is probably sufficient enough to cause garbling of a message if the message is longer than the clear window time.

Because of the relatively flat bottom in the Nanoose tracking area, and the detailed depth information, placement of the projectors four yards from the bottom should be possible in Nanoose Bay. Except for the steep rise in the area of tracking hydrophone -07, multipath interference should result only from the surface-bottom reflected rays, and the clear time window contours shown in Figure 40 can be used to predict the clear time windows in Nanoose.

5.0 RESULTS AND CONCLUSIONS

5.1 RESULTS OF MULTIPATH INTERFERENCE PREDICTION STUDY FOR DABOB AND NANOOSE SONAR CHANNELS

5.1.1 Dabob Bay

1. Because of the characteristics of the velocity profiles, the effective radius of interference free coverage per UQC projector is 1250 yards to 1750 yards at a receiver depth of 300 feet depending upon the depth of the projector and bottom slope. This requires four or five projectors to effectively cover the same area as is covered by the 3-D tracking hydrophones. Since the bottom depth contours are not known in detail at the present time, the exact number of the UQC projectors was not determined.

2. Clear time windows of greater than 40 msec can be expected for a four or five projector system providing:

   a. The beam patterns for the projectors are limited to a hemisphere looking upward.

   b. The beam patterns for the receive hydrophones are limited to a hemisphere looking downward.

5.1.2 Nanoose Bay

1. Because of the characteristics of the velocity profiles, the effective radius of interference free coverage per UQC projector located four yards from the bottom is 2600 yards at a receiver depth of 1000 feet. This requires five UQC projectors to cover the 3-D tracking range.

2. Clear time windows of greater than 100 msec can be expected for a five projector system providing the beam patterns for the projectors and receive hydrophones are limited as in Dabob Bay.

5.2 CONCLUSIONS

5.2.1 The existence of clear time windows of these magnitudes make a communication technique feasible. In this technique, a projector nearest the submarine will be used to communicate a message of 40 msec length in Dabob Bay and 100 msec length in Nanoose Bay. The repetition rate of messages will be determined by the reverberation decay times which are unknown at the present time. However, an assumption of 600 msec for Dabob Bay makes a data rate of 67 bits per second feasible. An assumption of one second for Nanoose Bay makes a data rate of 100 bits per second feasible.

5.2.2 Direct ray coverage and clear time windows in both Dabob Bay and Nanoose Bay were predicted from a relatively small sample of velocity profiles. More velocity profiles of both bays are needed in order to make more accurate predictions. Also, in order to verify the predictions it is recommended that tests be made in both bays to measure clear time windows, effective coverage radius of projectors and reverberation decay times.

REFERENCES

1. R. H. Adlington, "Acoustics - Reflection Losses at the Sea Surface, Measured with Explosive Sources," J. Acoust. Soc. Am., 19:8 (1947).

2. R. J. Urick and N. L. Saxton, "Surface Reflection of Short Supersonic Pulses in the Ocean," J. Acoust. Soc. Am., 19:8 (1947).

3. M. E. Scharer, "A Continuous Gradient Sound Velocity Curve Fitting Routine - User's Guide for Program Profile," Librascope Report No. 6286, September 5, 1969.

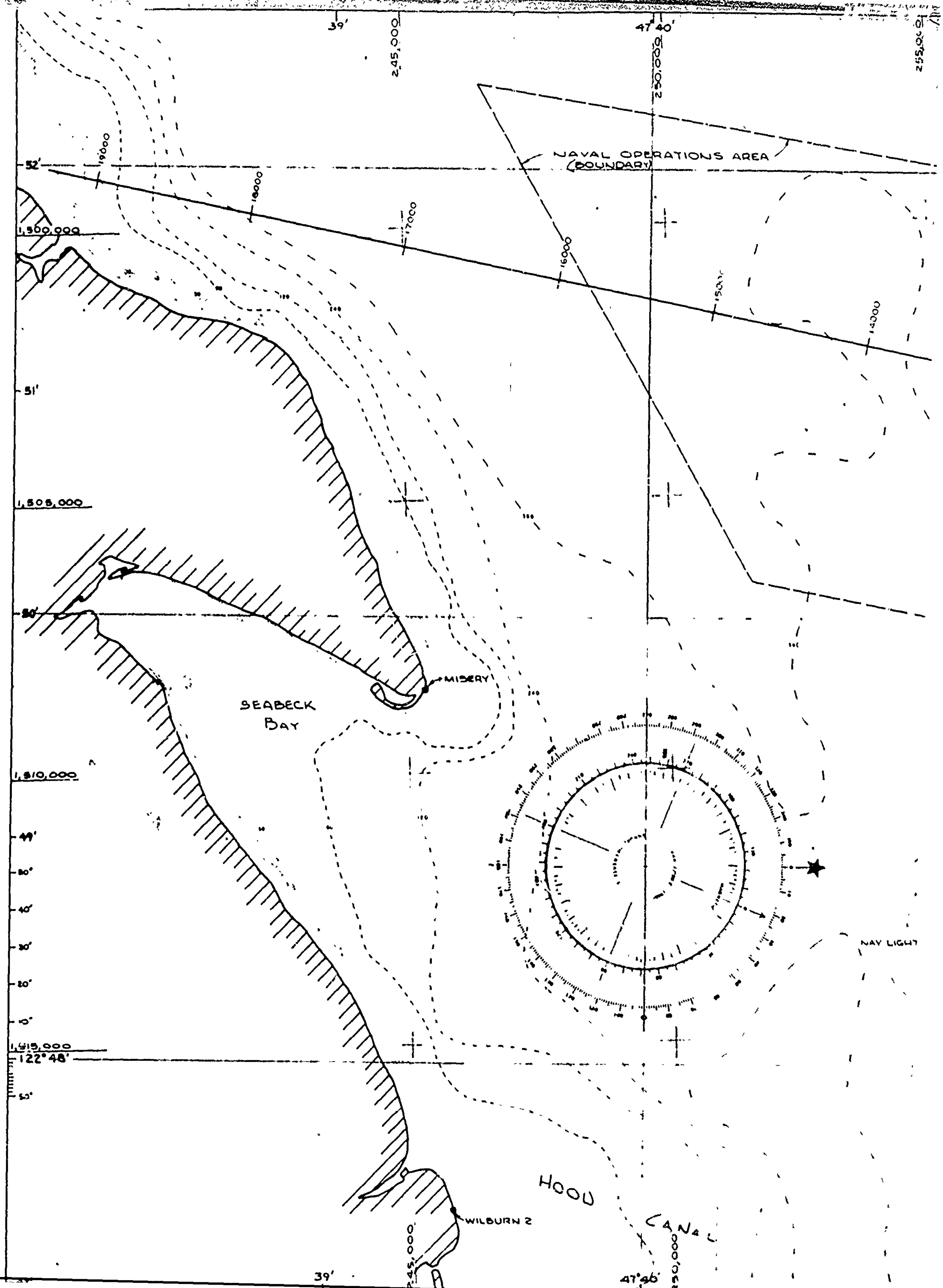
4. M. E. Scharer, "Users Guide for Curvilinear Profile Ray Trace Program," Librascope Report LIBI 6271, June 18, 1969.

5. C. B. Officer, "Introduction to the Theory of Sound Transmissions," McGraw-Hill Book Company, New York, 1958.

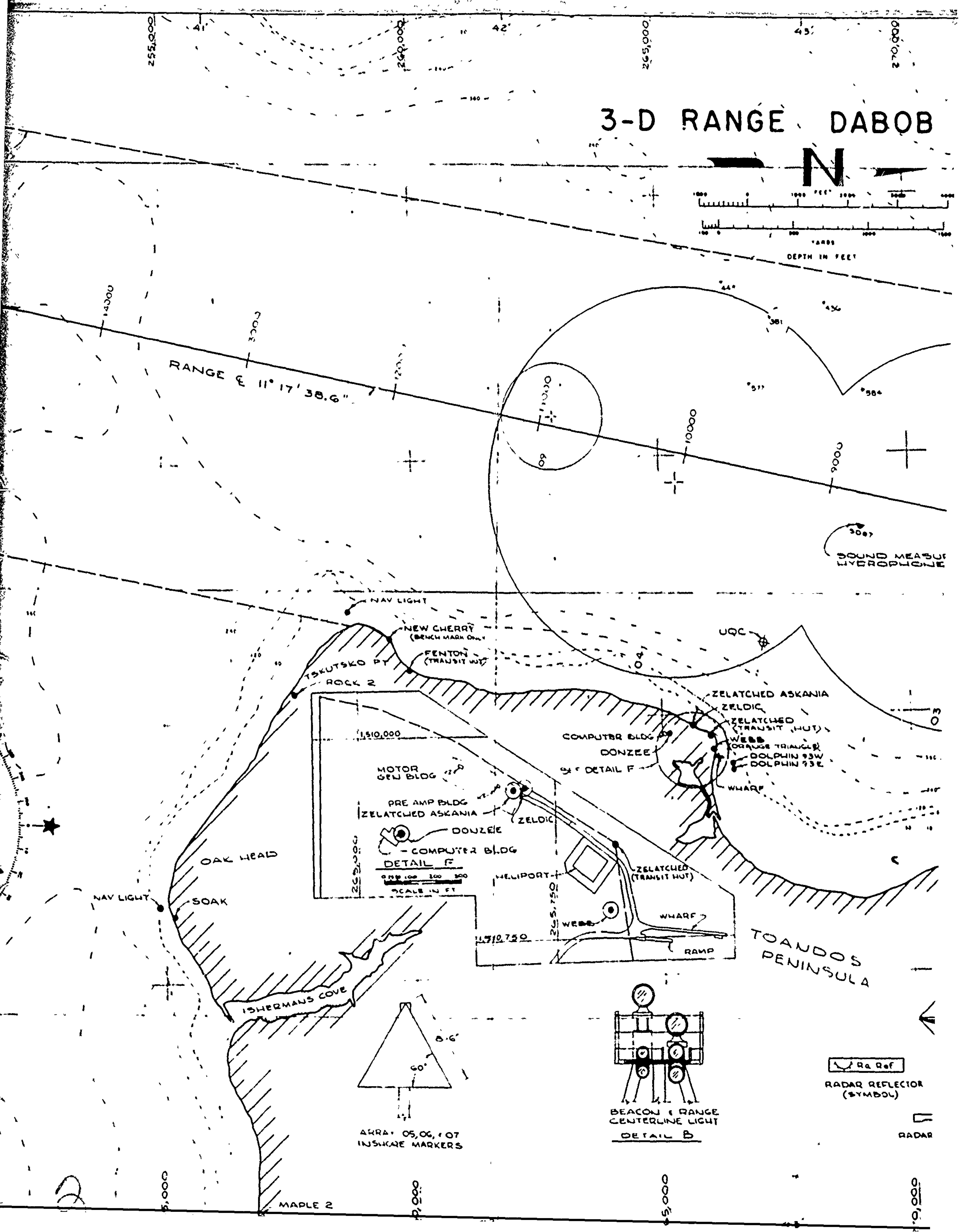
Table 1. Dabob Bay Bottom Loss*

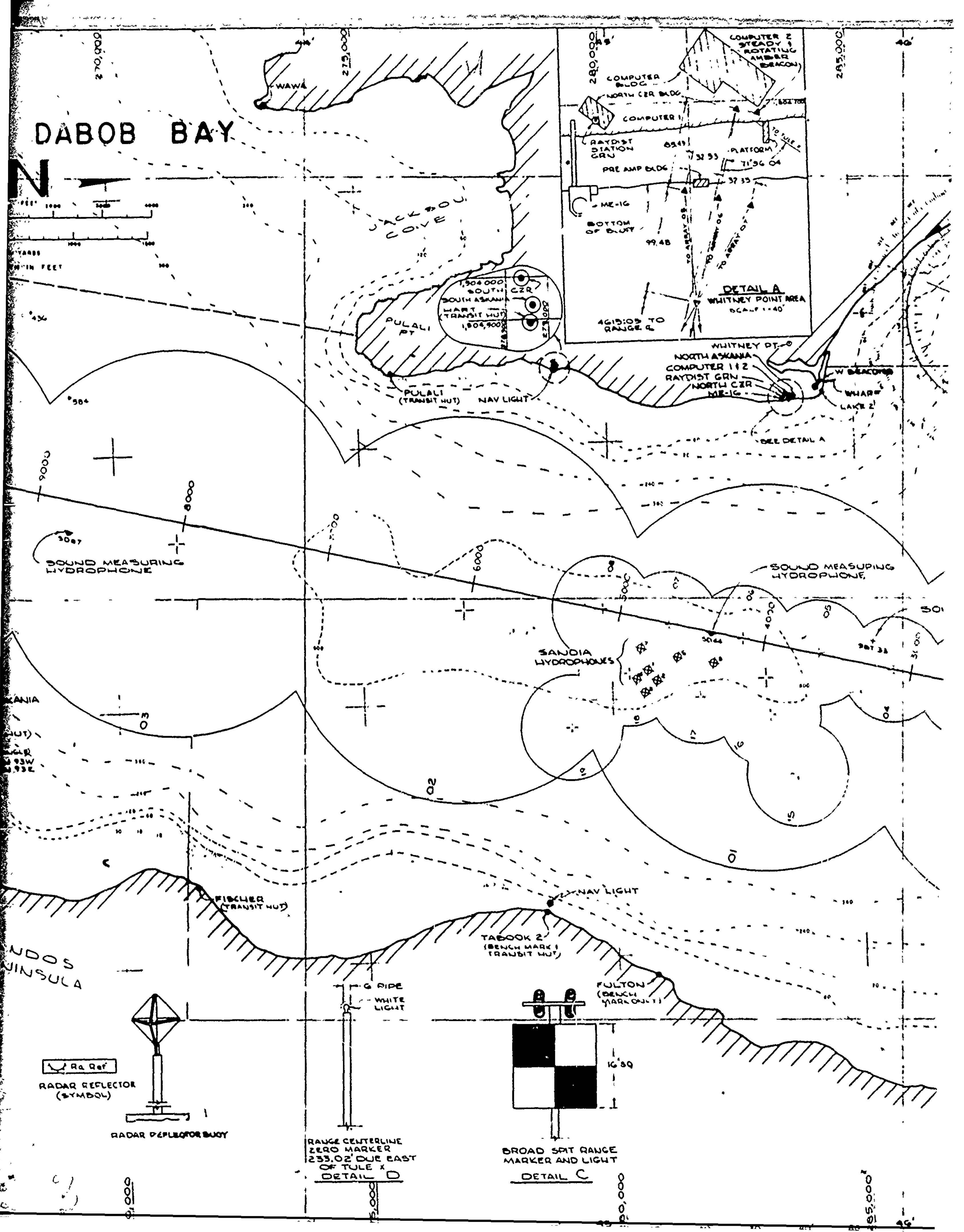
GRAZING ANGLE	BOTTOM LOSS
0°	0-1 db
10°	1-1.5 db
30°	3-4 db
45°	4-6 db
60°	5-8 db

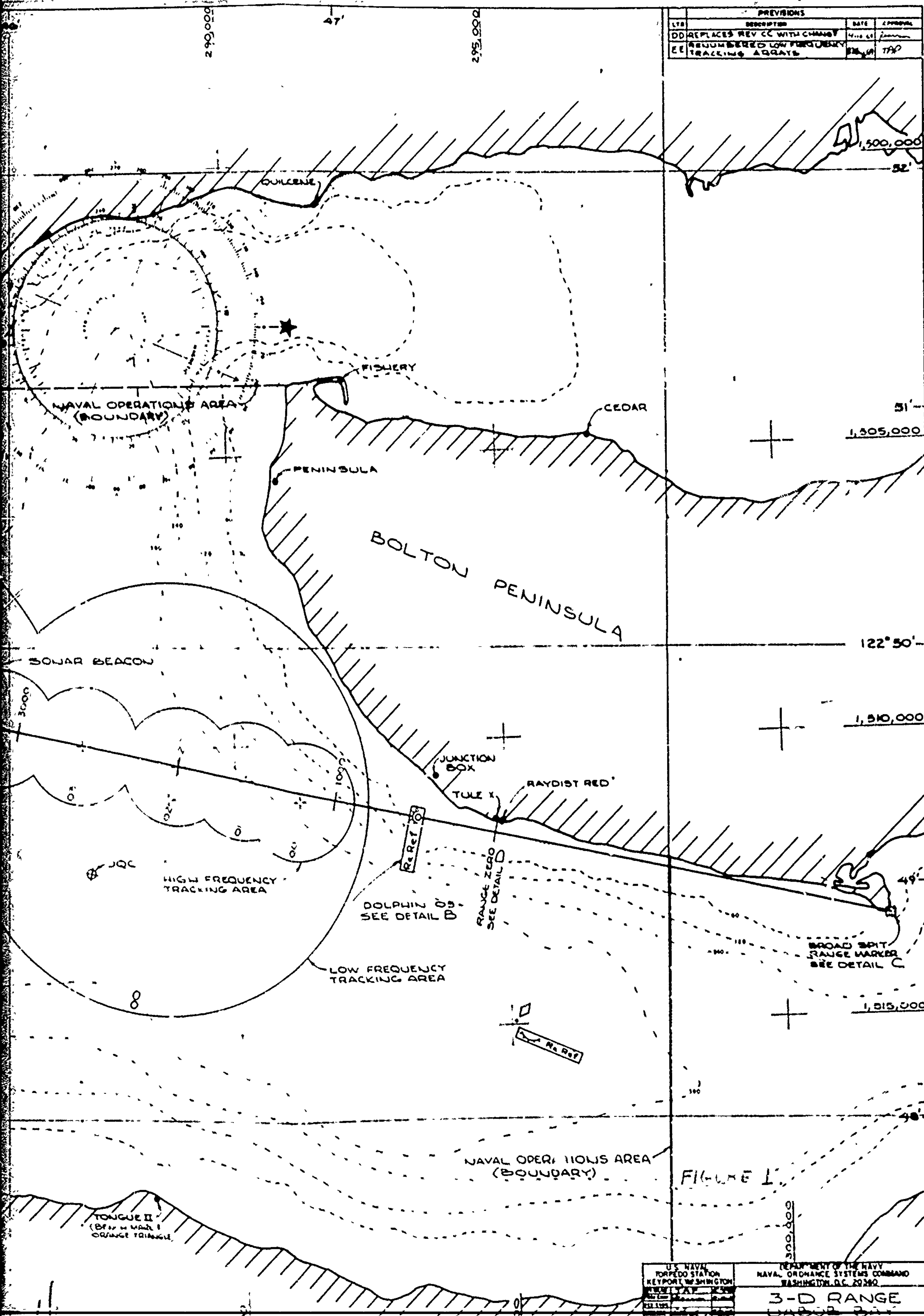
*NOTE: This data is an excerpt from a Bolt, Beraner and Newman, Inc. report. The title and date of the report are unknown.

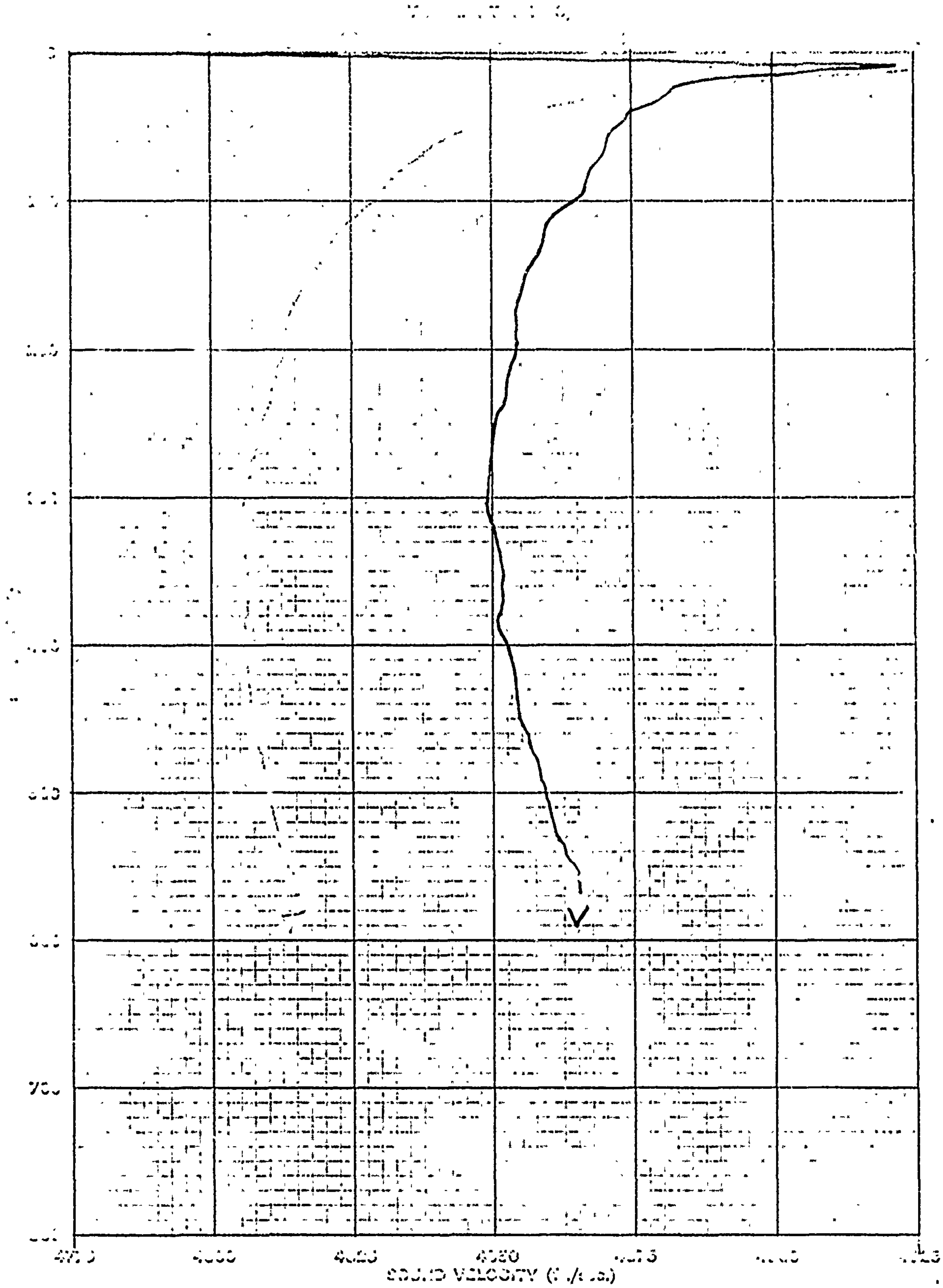


39'
245,000
47°40'
250,000
255,000
NAVAL OPERATIONS AREA
(BOUNDARY)
52'
19000
18000
17000
16000
15000
14000
1,500,000
51'
1,505,000
50'
MISERY
SEABECK
BAY
1,510,000
49'
50"
40"
30"
20"
10"
1,515,000
122°48'
50"
NAV LIGHT
HOOD
CANAL
WILBURN 2
245,000
39'
47°46'
250,000


3-D RANGE DABOB
N
FEET
YARDS
DEPTH IN FEET
255,000
260,000
265,000
270,000
41'
42'
43'
RANGE ℄ 11° 17' 38.6"
SOUND MEASU
HYDROPHONE
NAV LIGHT
NEW CHERRY (BENCH MARK ONLY)
FENTON (TRANSIT HUT)
TSKUTSKO PT
ROCK 2
UQC
ZELATCHED ASKANIA
ZELDIC
ZELATCHED (TRANSIT HUT)
WEBB (ORANGE TRIANGLE)
DOLPHIN 93W
DOLPHIN 93E
WHARF
COMPUTER BLDG
DONZEE
SEE DETAIL F
1,510,000
MOTOR GEN BLDG
PRE AMP BLDG
ZELATCHED ASKANIA
ZELDIC
DONZEE
COMPUTER BLDG
DETAIL F
SCALE IN FT
HELIPORT
ZELATCHED (TRANSIT HUT)
WEBB
WHARF
RAMP
1,510,750
265,750
OAK HEAD
NAV LIGHT
SOAK
FISHERMANS COVE
TOANDOS PENINSULA
8.6'
60°
ARRAY 05, 06, & 07
INSHORE MARKERS
BEACON & RANGE
CENTERLINE LIGHT
DETAIL B
Ra Ref
RADAR REFLECTOR
(SYMBOL)
RADAR
MAPLE 2


DABOB BAY
N
WAWA
JACKSON COVE
PULALI PT
SOUTH CZR
SOUTH ASKANIA
HART (TRANSIT HUT)
PULALI (TRANSIT HUT)
NAV LIGHT
WHITNEY PT
NORTH ASKANIA
COMPUTER 1 & 2
RAYDIST GRN
NORTH CZR
ME-16
SEE DETAIL A
W BEACON
WHARF
LAKE 2
COMPUTER 2 STEADY & ROTATING AMBER BEACON
COMPUTER BLDG
NORTH CZR BLDG
COMPUTER 1
RAYDIST STATION GRN
PLATFORM
PRE AMP BLDG
ME-16
BOTTOM OF BLUFF
TO ARRAY 08
TO ARRAY 06
TO ARRAY 07
DETAIL A
WHITNEY POINT AREA
SCALE 1" = 40'
RANGE ℄
SOUND MEASURING HYDROPHONE
SANDIA HYDROPHONES
SOUND MEASURING HYDROPHONE
FISCHER (TRANSIT HUT)
NAV LIGHT
TABOOK 2 (BENCH MARK & TRANSIT HUT)
FULTON (BENCH MARK ONLY)
TOANDOS PENINSULA
Ra Ref
RADAR REFLECTOR (SYMBOL)
RADAR REFLECTOR BUOY
G PIPE
WHITE LIGHT
RANGE CENTERLINE ZERO MARKER 233.02' DUE EAST OF TULE X
DETAIL D
16'SQ
BROAD SPIT RANGE MARKER AND LIGHT
DETAIL C
270,000
275,000
280,000
285,000

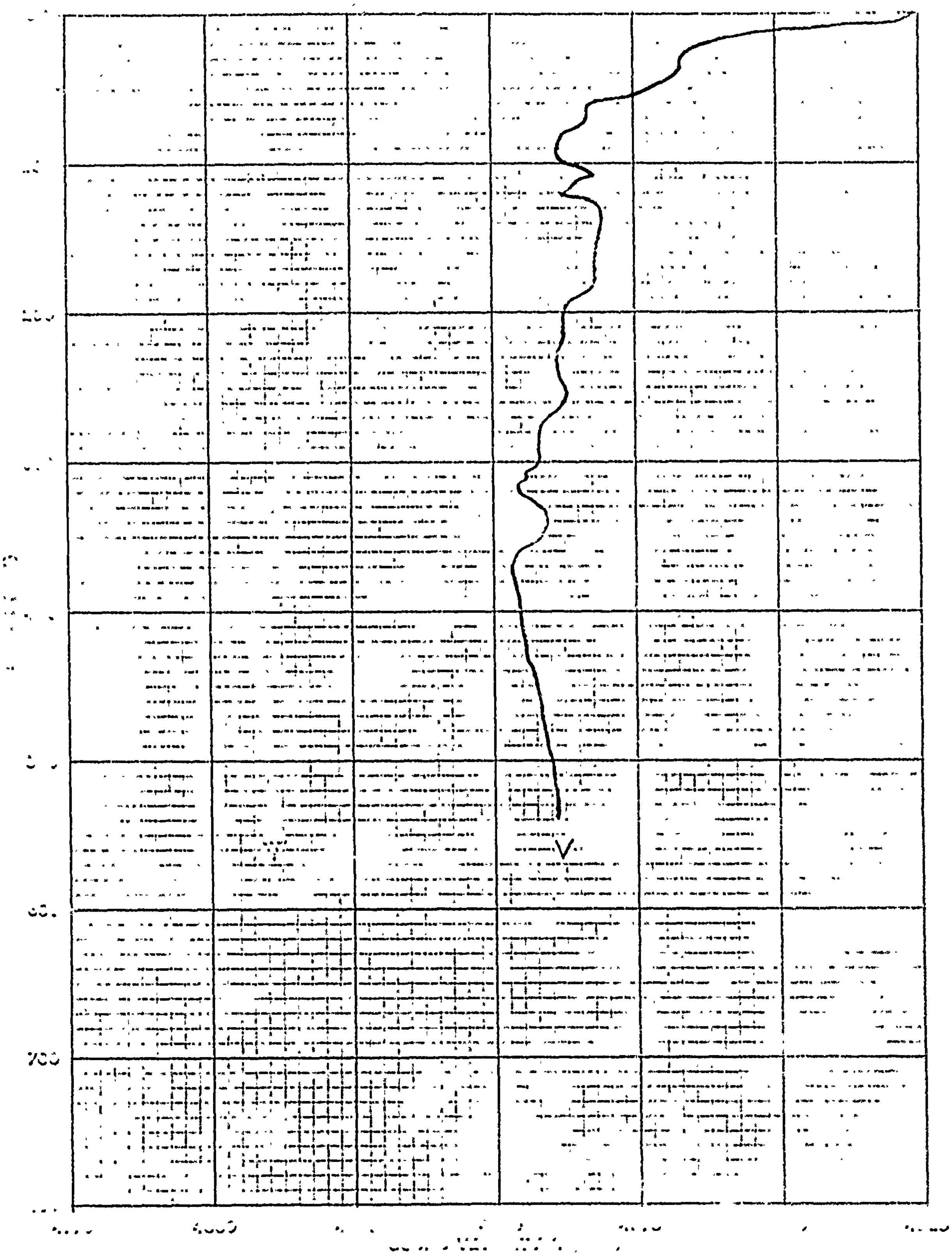

REVISIONS
DD REPLACES REV CC WITH CHANGE
EE RENUMBERED LOW FREQUENCY TRACKING ARRAYS
290,000
47'
295,000
1,500,000
52'
QUILCENE
FISHERY
NAVAL OPERATIONS AREA (BOUNDARY)
CEDAR
51'
1,505,000
PENINSULA
BOLTON PENINSULA
122°50'
SONAR BEACON
1,510,000
JUNCTION BOX
RAYDIST RED
TULE X
JQC
HIGH FREQUENCY TRACKING AREA
DOLPHIN 05 SEE DETAIL B
RANGE ZERO SEE DETAIL D
49'
BROAD SPIT RANGE MARKER SEE DETAIL C
LOW FREQUENCY TRACKING AREA
1,515,000
48'
NAVAL OPERATIONS AREA (BOUNDARY)
FIGURE 1
TONGUE II
300,000
U.S. NAVAL TORPEDO STATION KEYPORT, WASHINGTON
DEPARTMENT OF THE NAVY NAVAL ORDNANCE SYSTEMS COMMAND WASHINGTON, D.C. 20360
3-D RANGE



DABOB 17 JUNE 69 10000

VELOCITY/TEMPERATURE 0840

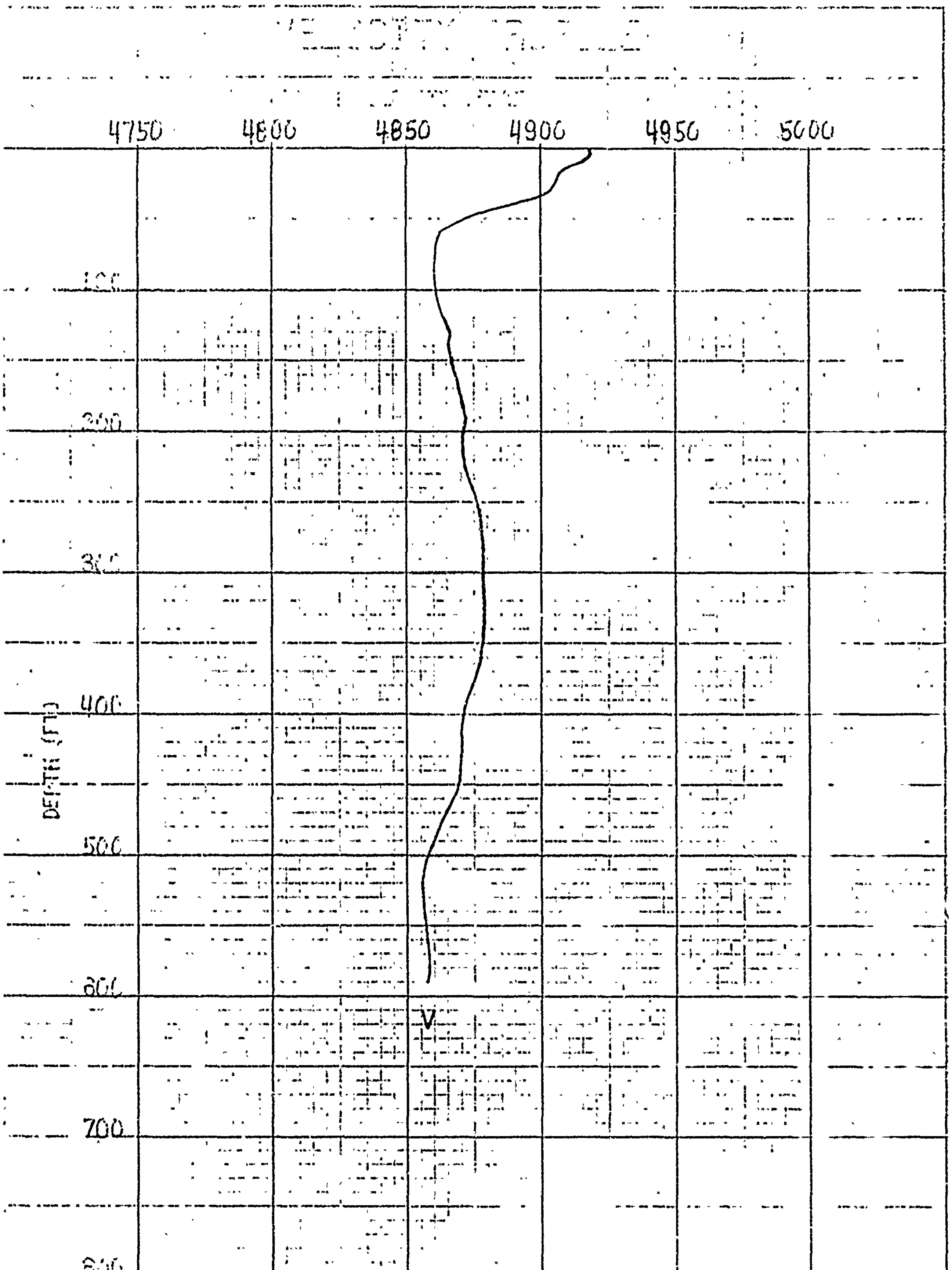
FIGURE 2 : DABOB VELOCITY PROFILE D-1



RANGE: DABOB 1 AUG 69 10.000

1020

FIGURE 3. DABOB VELOCITY PROFILE D-2



RANGE	DATE	POSITION X	Y
DABOB	08-25-69	4000	

FIGURE. 4. DABOB VELOCITY PROFILE D-3

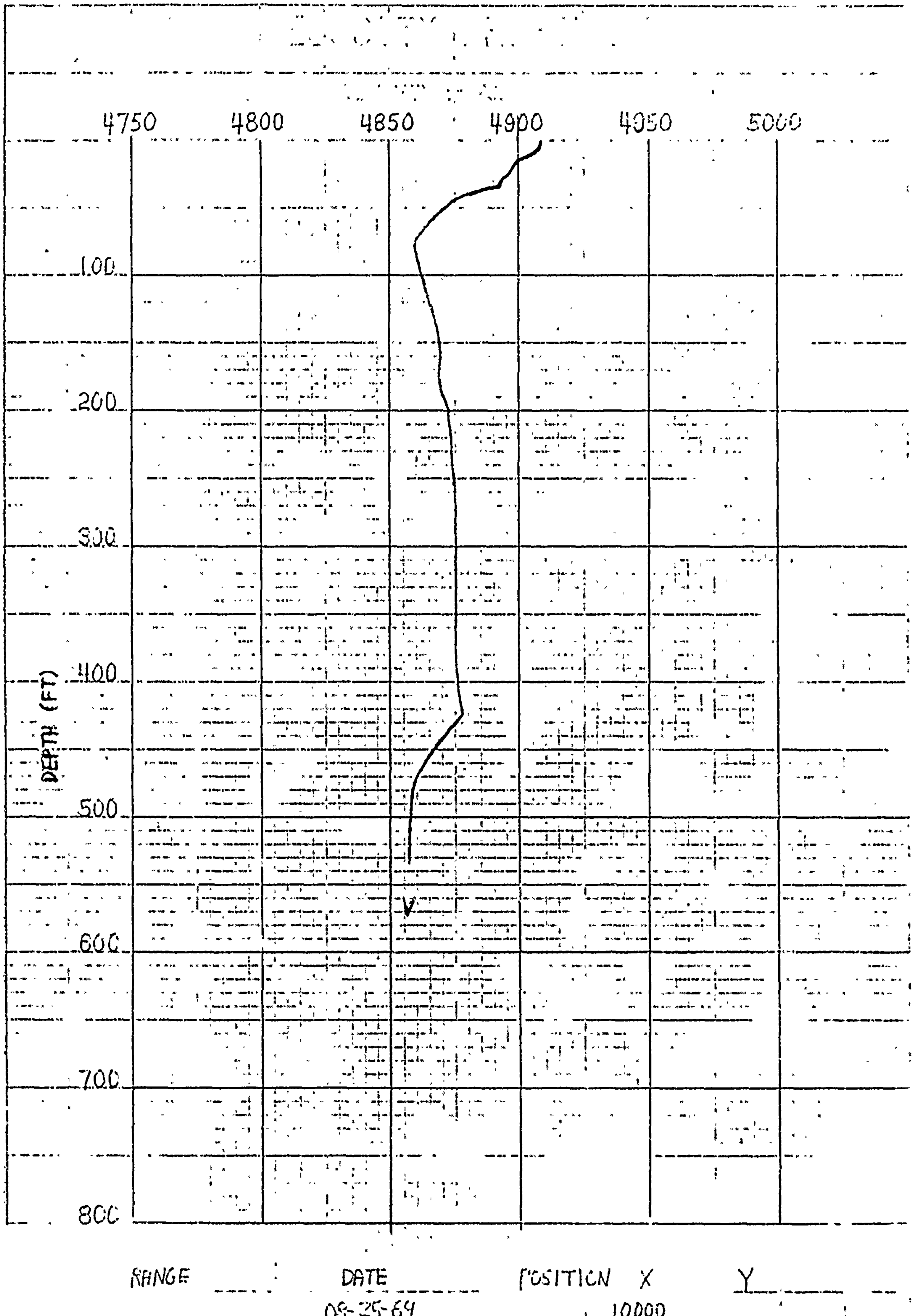
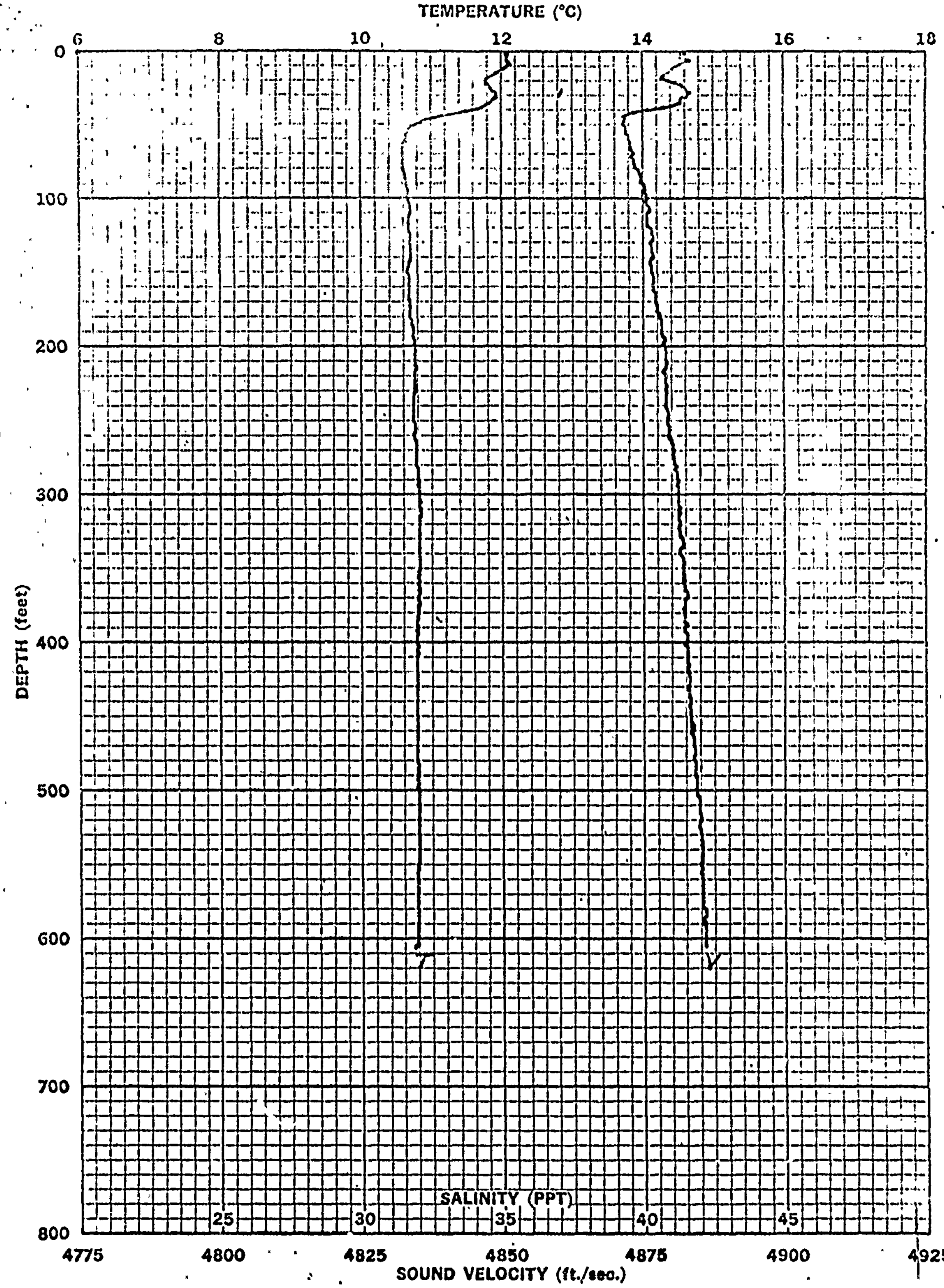


FIGURE 5. DABOB VELOCITY PROFILE D-4

REPORT

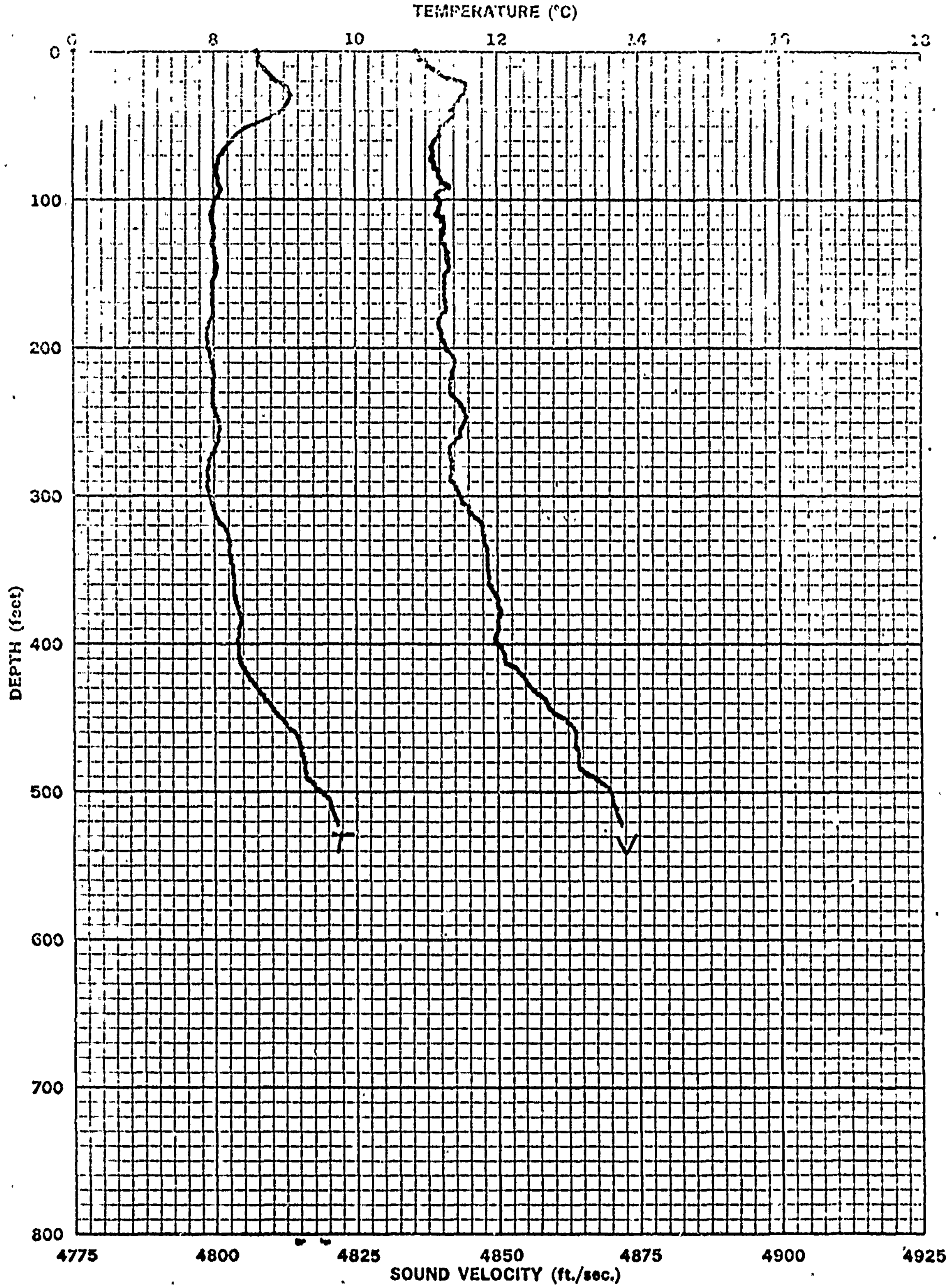


RANGE: DABOB DATE: 10-10-69 POSIT: 6000

FIG. VELOCITY/TEMPERATURE PROFILE

0850

FIGURE 6. DABOB VELOCITY PROFILE D-5

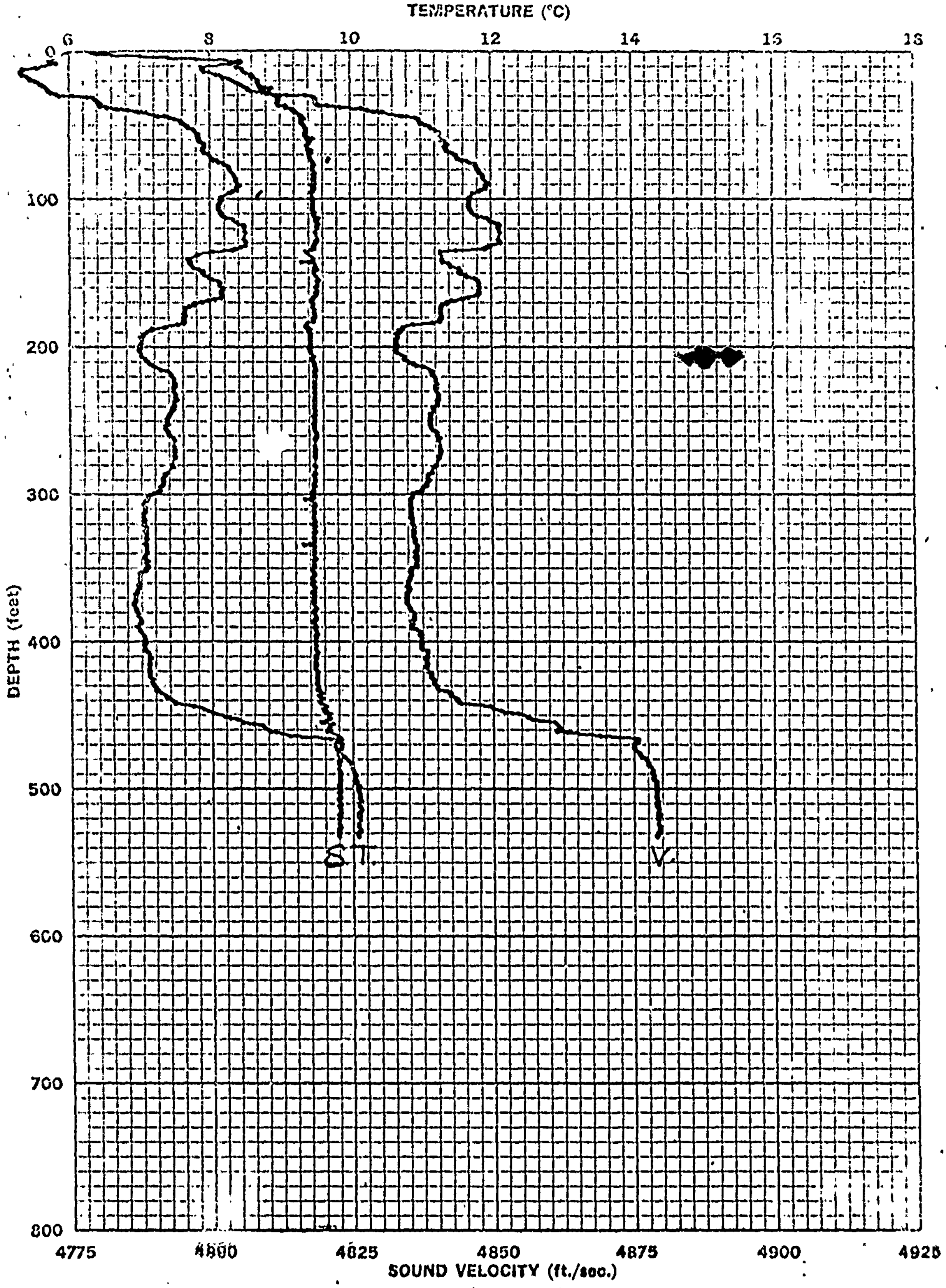


RANGE: DABOB DATE: 4-2-69 POSIT: 9800

FIG. VELOCITY/TEMPERATURE PROFILE

TIME 0730

FIGURE 7. DABOB VELOCITY PROFILE D-6



RANGE: DABOB DATE: 13 FEB 1969 POSIT: 10,000 200 E

FIG. VELOCITY/TEMPERATURE PROFILE TIME 0807

FIGURE 8. DABOB VELOCITY PROFILE D-7

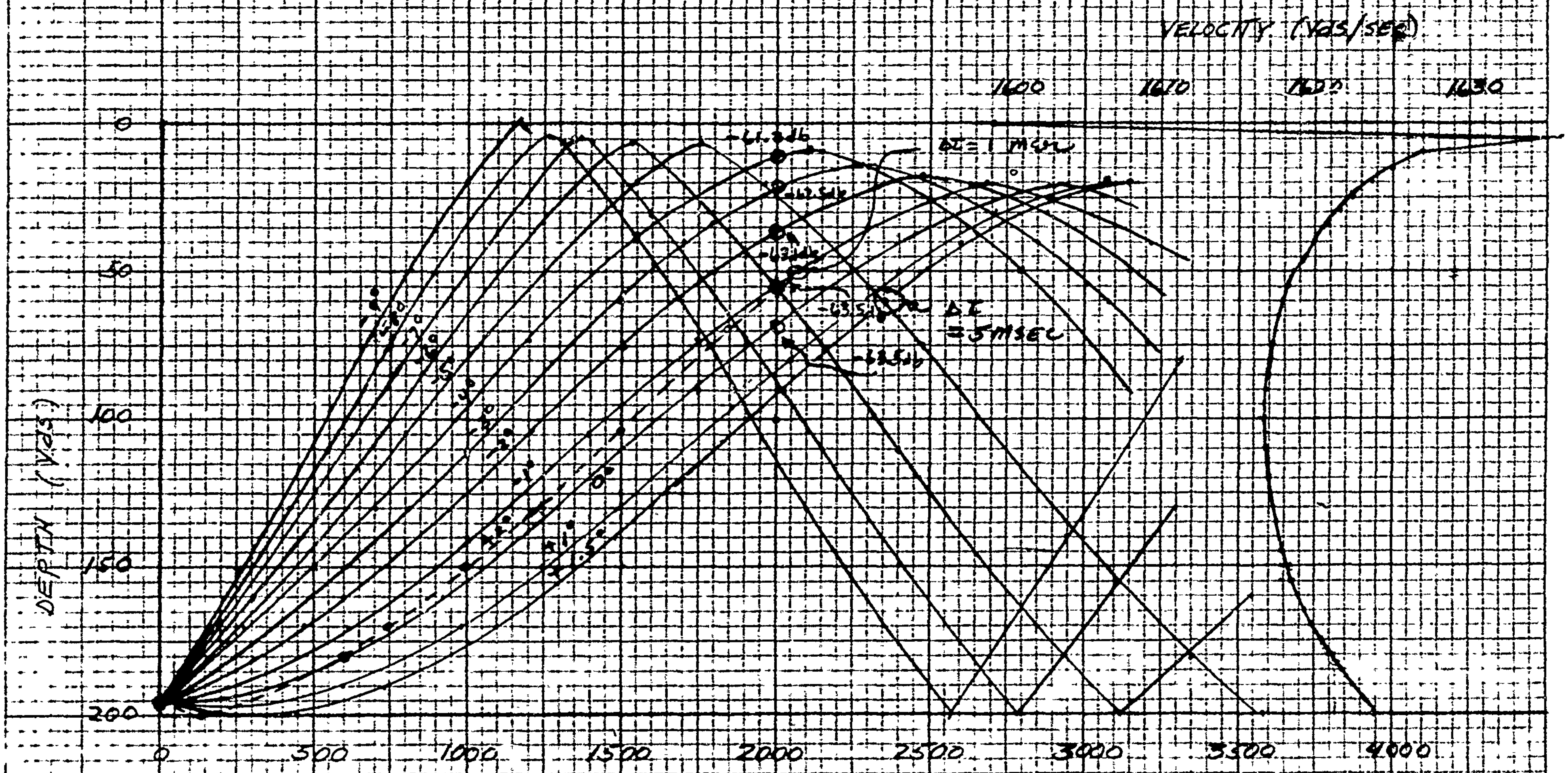


FIGURE 9.

DABOB BAY VELOCITY PROFILE D-1
RAY TRACE

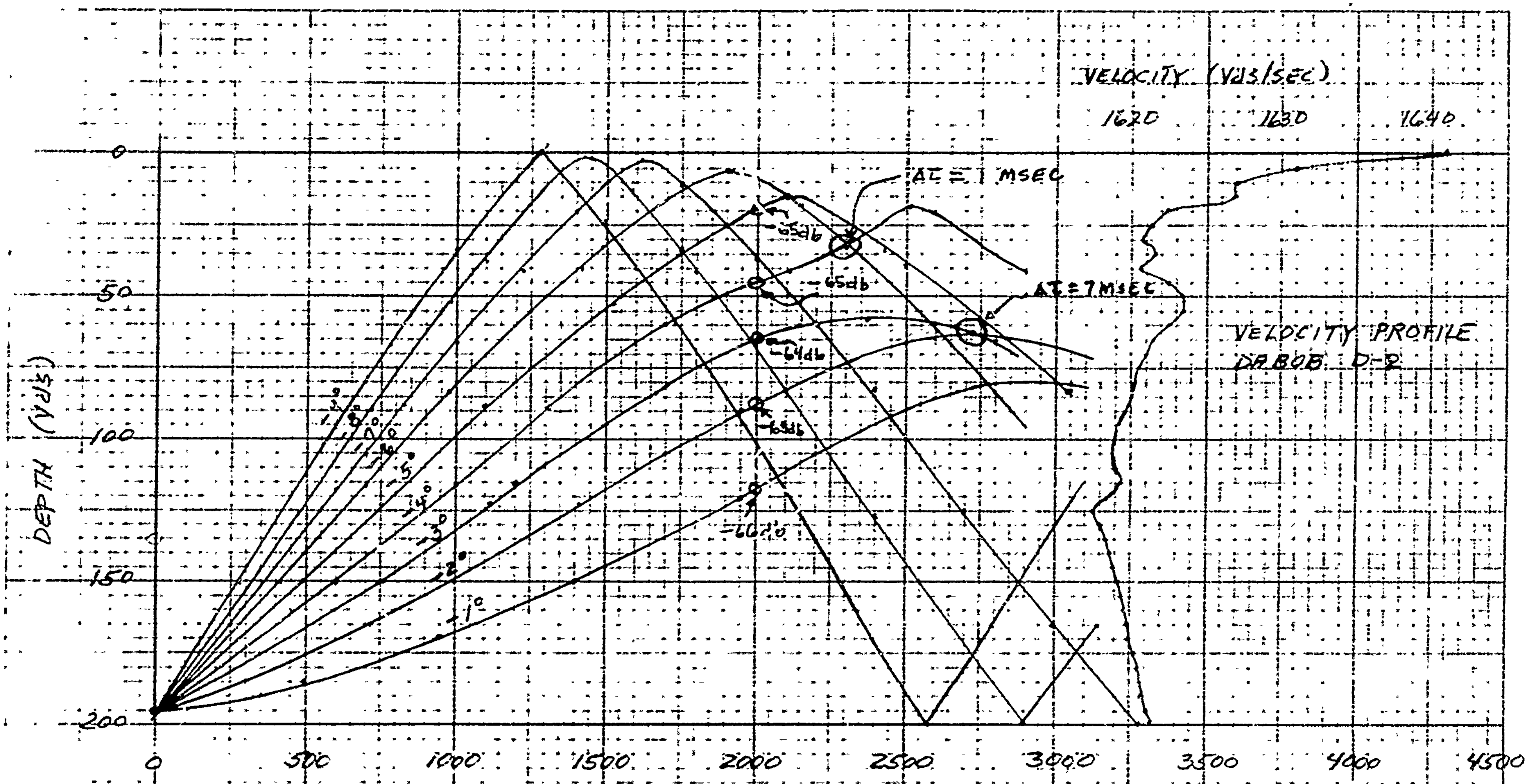


FIGURE 10.

DABOB BAY VELOCITY PROFILE D-2
RAY TRACE

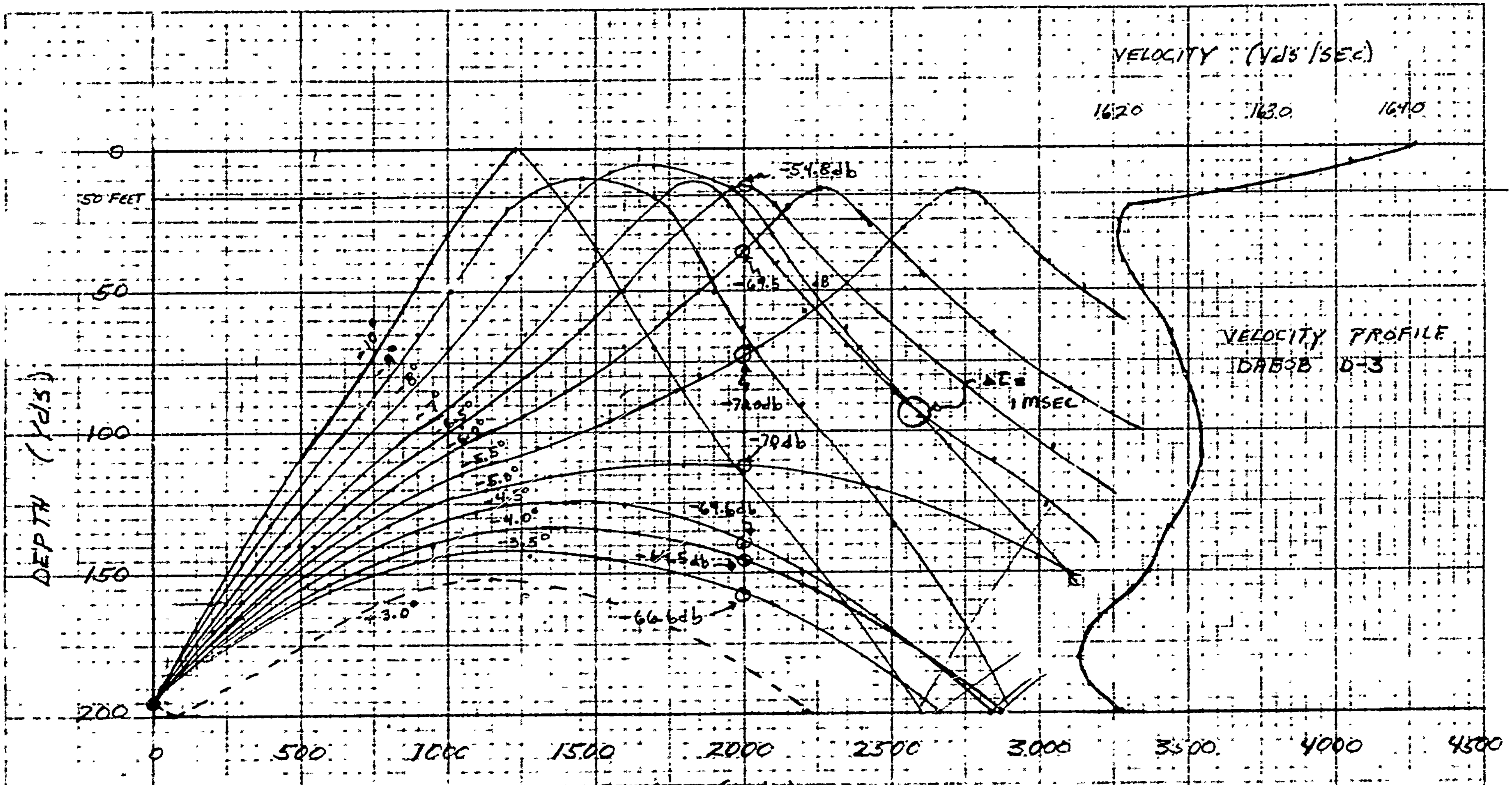


FIGURE 11.
DABOB BAY VELOCITY PROFILE D-3
RAY TRACE

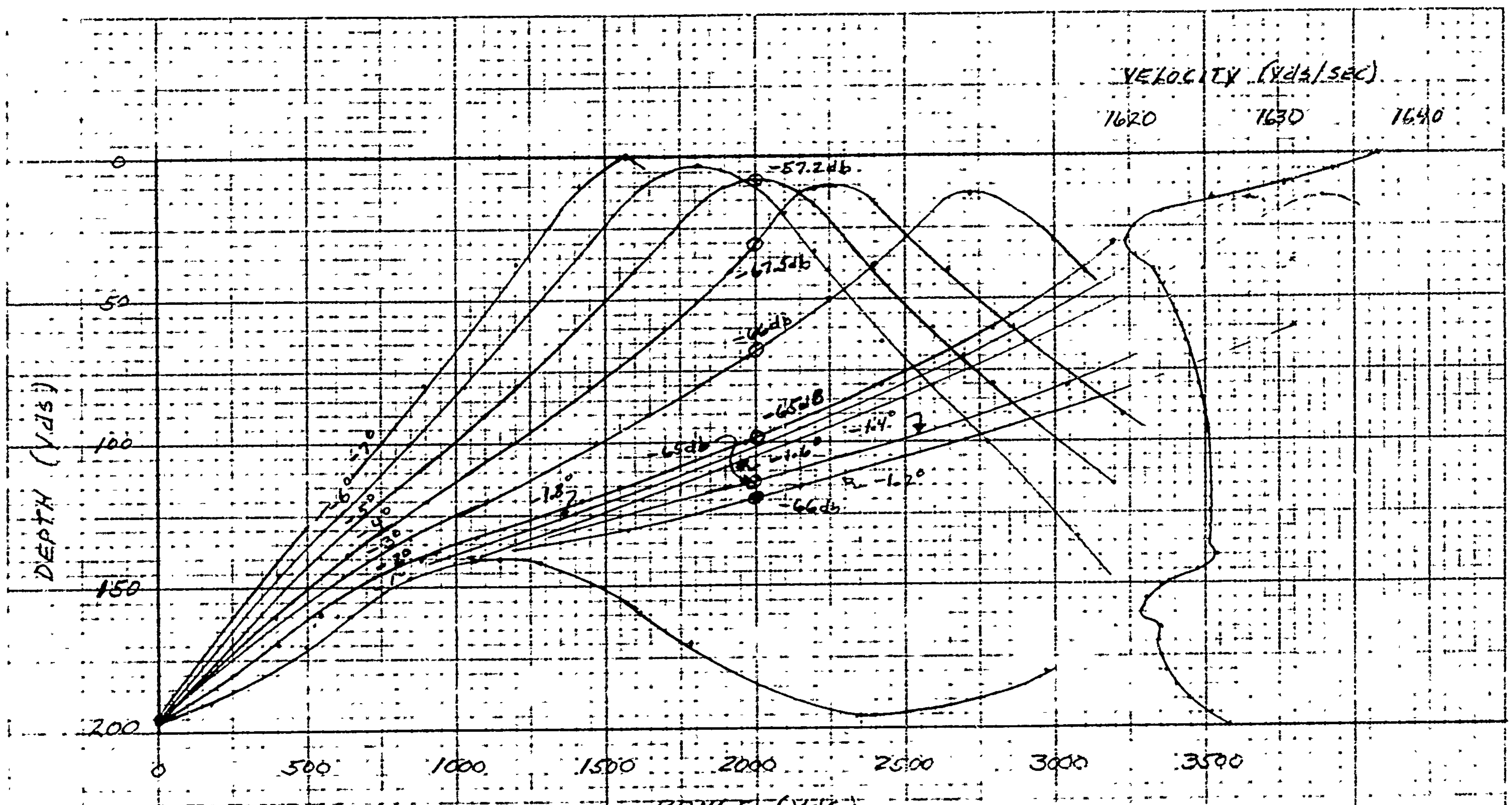


FIGURE 12.

DABOB BAY VELOCITY PROFILE D-4
RAY TRACE

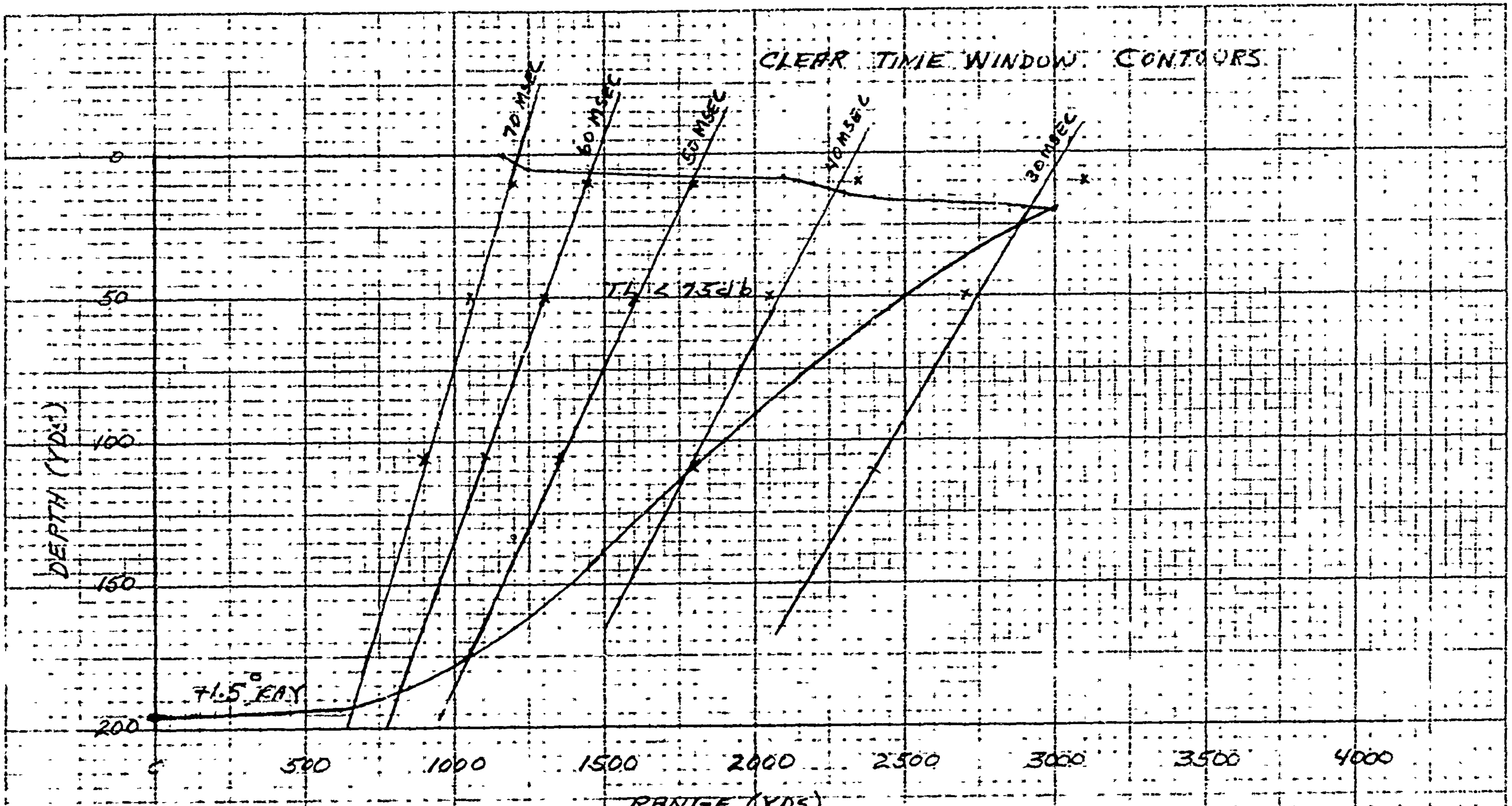


FIGURE 13.

DABOB BAY VELOCITY PROFILE D=1

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS; DOWNWARD LOOKING HYDROPHONE

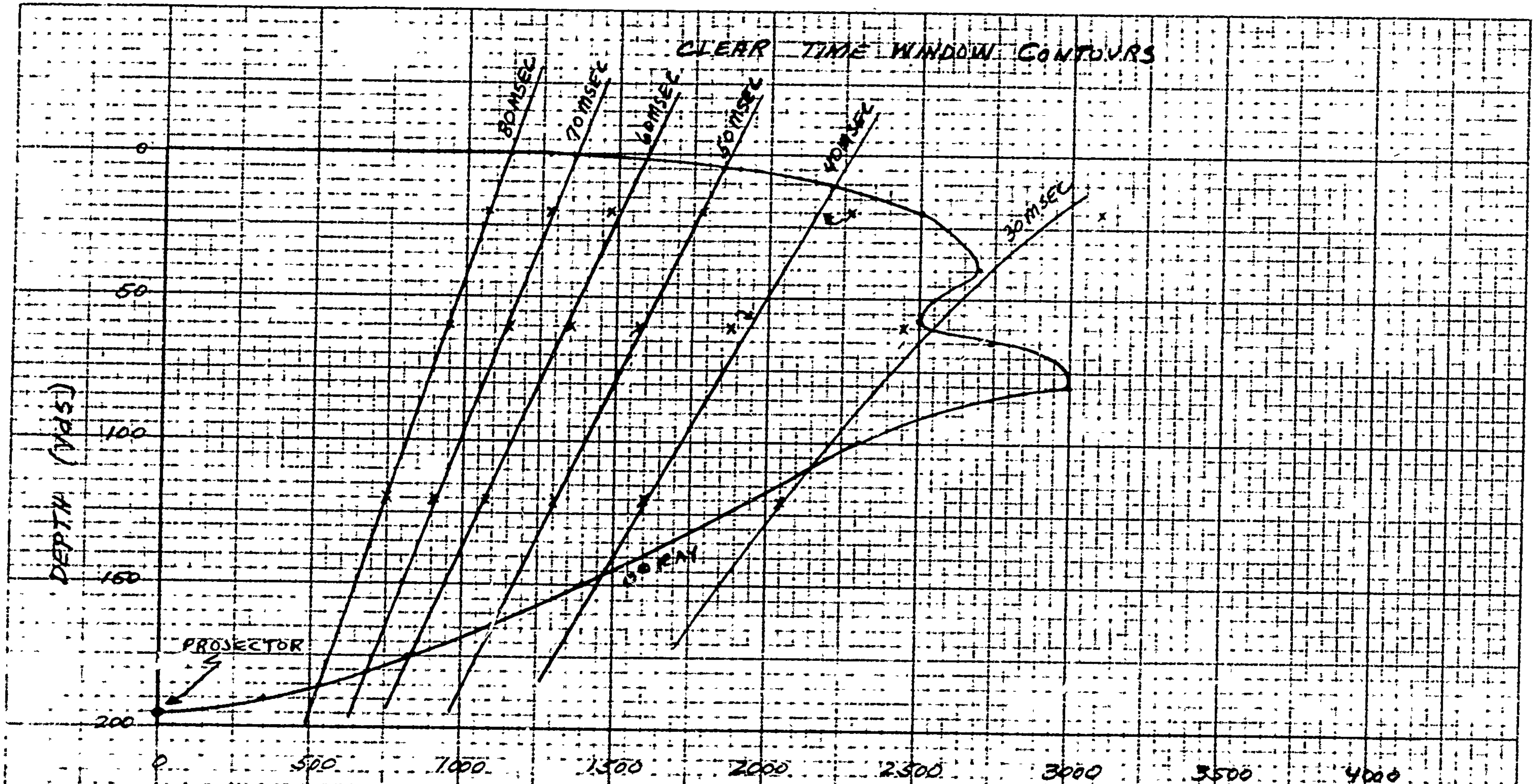


FIGURE 14.

DABOB BAY VELOCITY PROFILE D-2

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS; DOWNWARD LOOKING HYDROPHONE

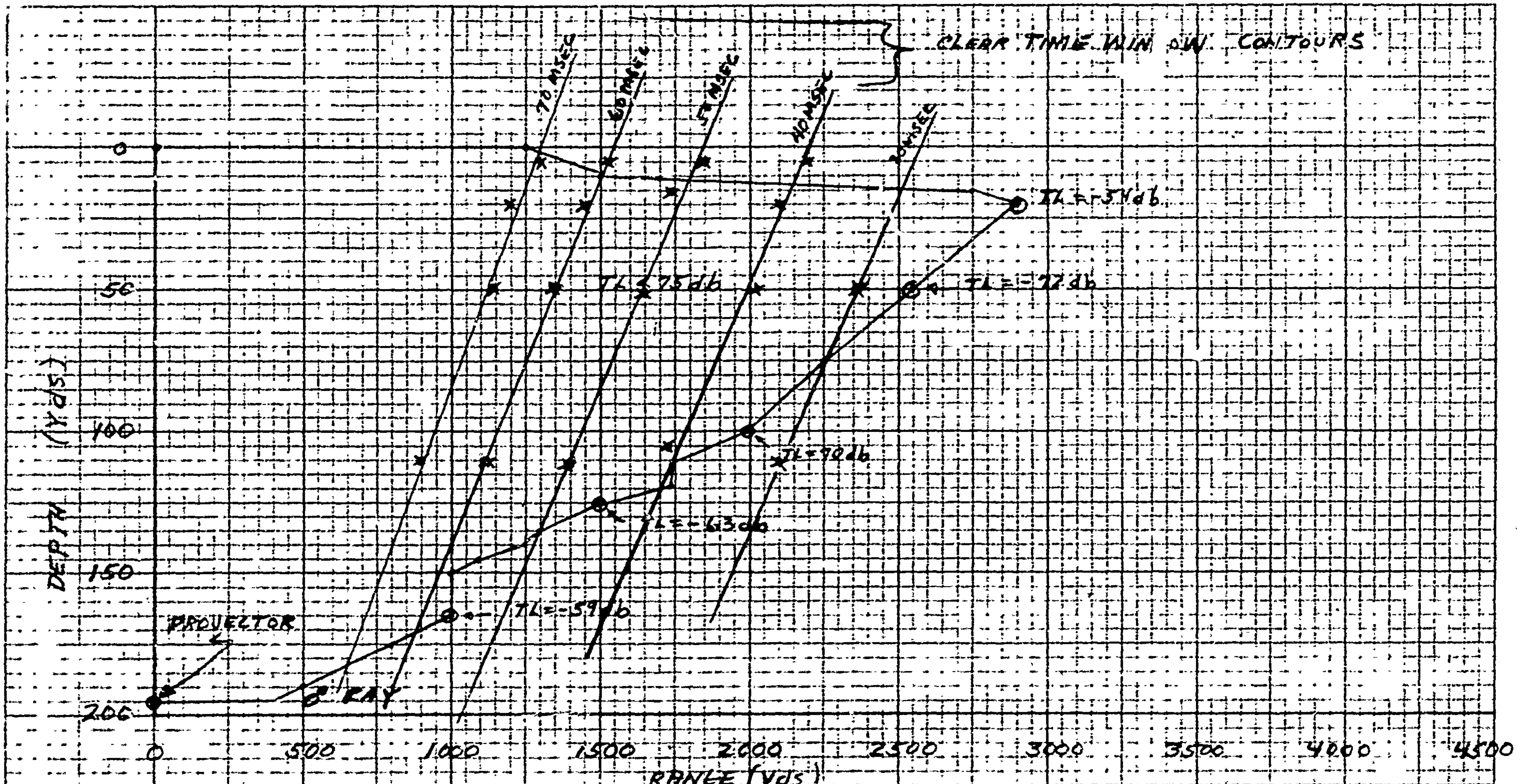


FIGURE 15.

DABOB BAY VELOCITY PROFILE D-3

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS; DOWNWARD LOOKING HYDROPHONE

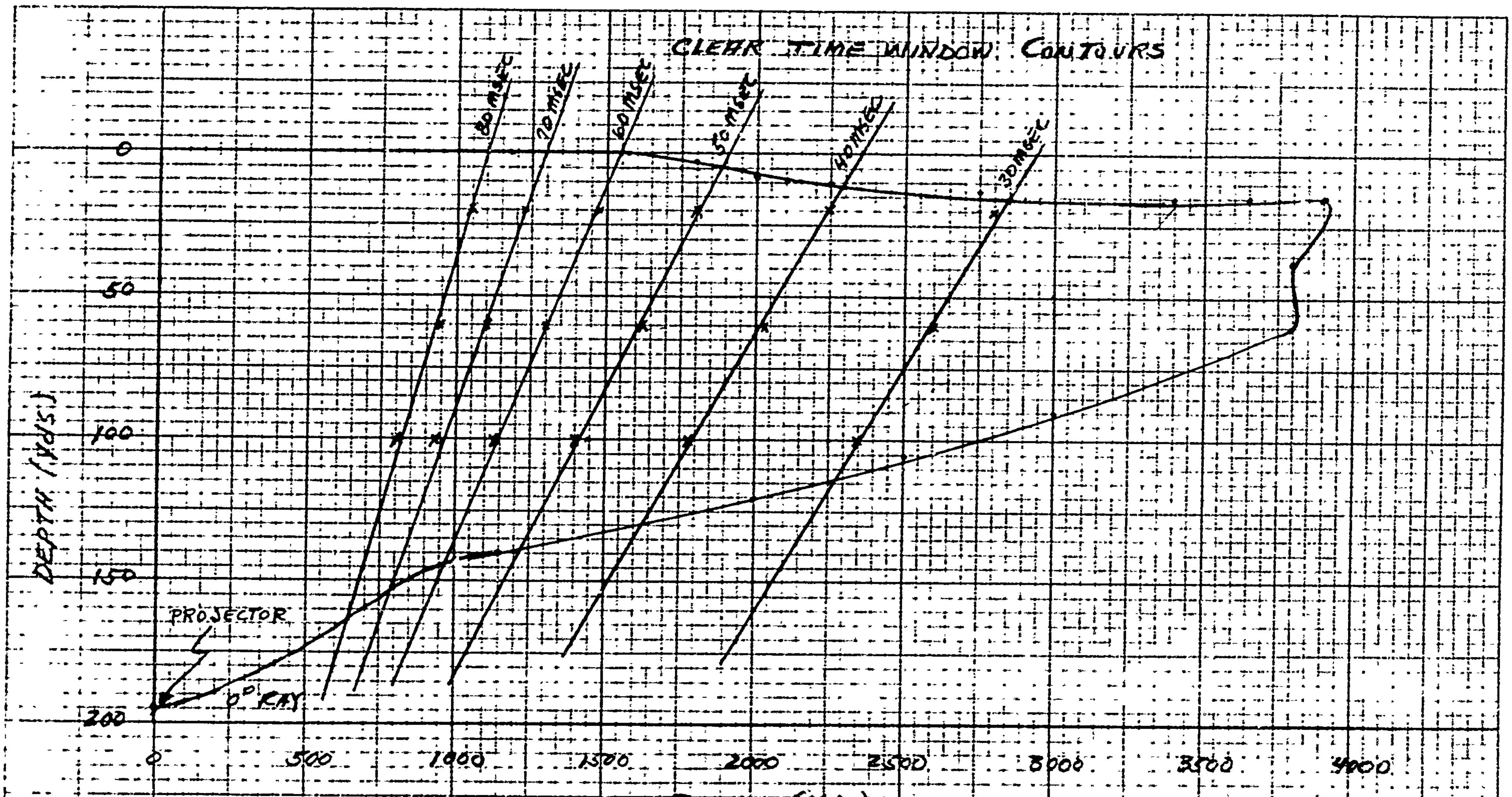


FIGURE 16.

DABOB BAY VELOCITY PROFILE D-4

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS; DOWNWARD LOOKING HYDROPHONE

D-5

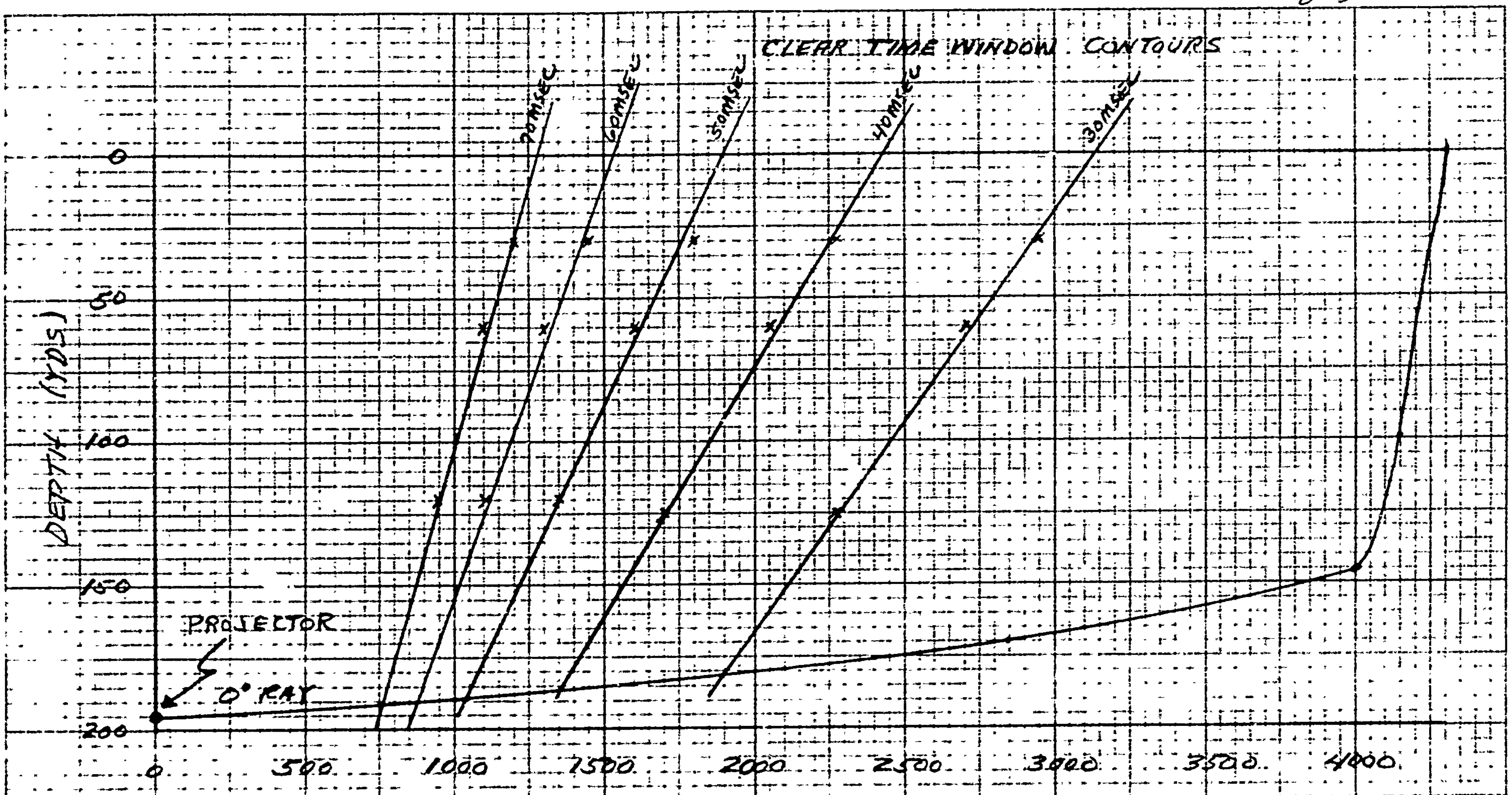


FIGURE 17.

DABOB BAY VELOCITY PROFILE D-5

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS;

DOWNWARD LOOKING HYDROPHONE

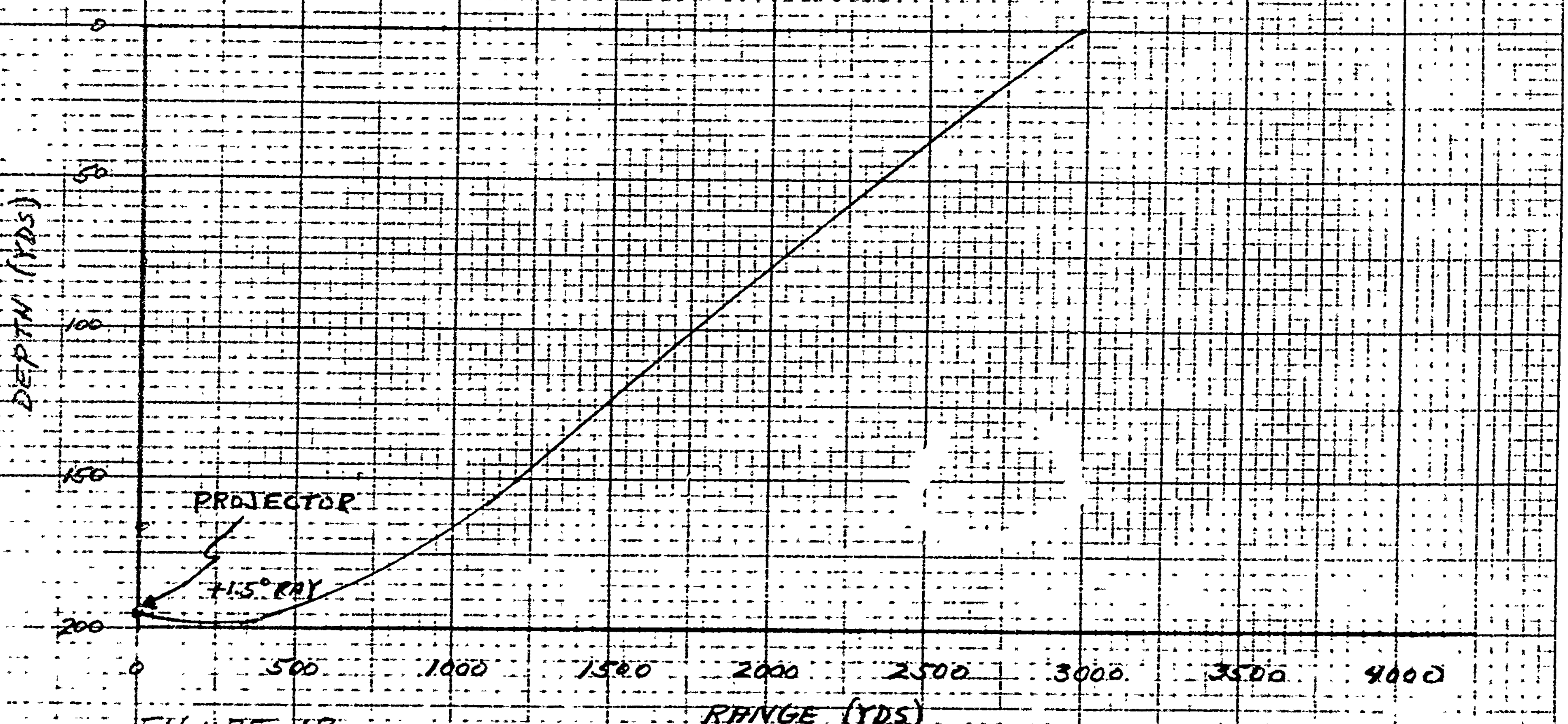


FIGURE 18.
DABOB BAY VELOCITY PROFILE D-6
MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS;
DOWNWARD LOOKING HYDROPHONE

D-7

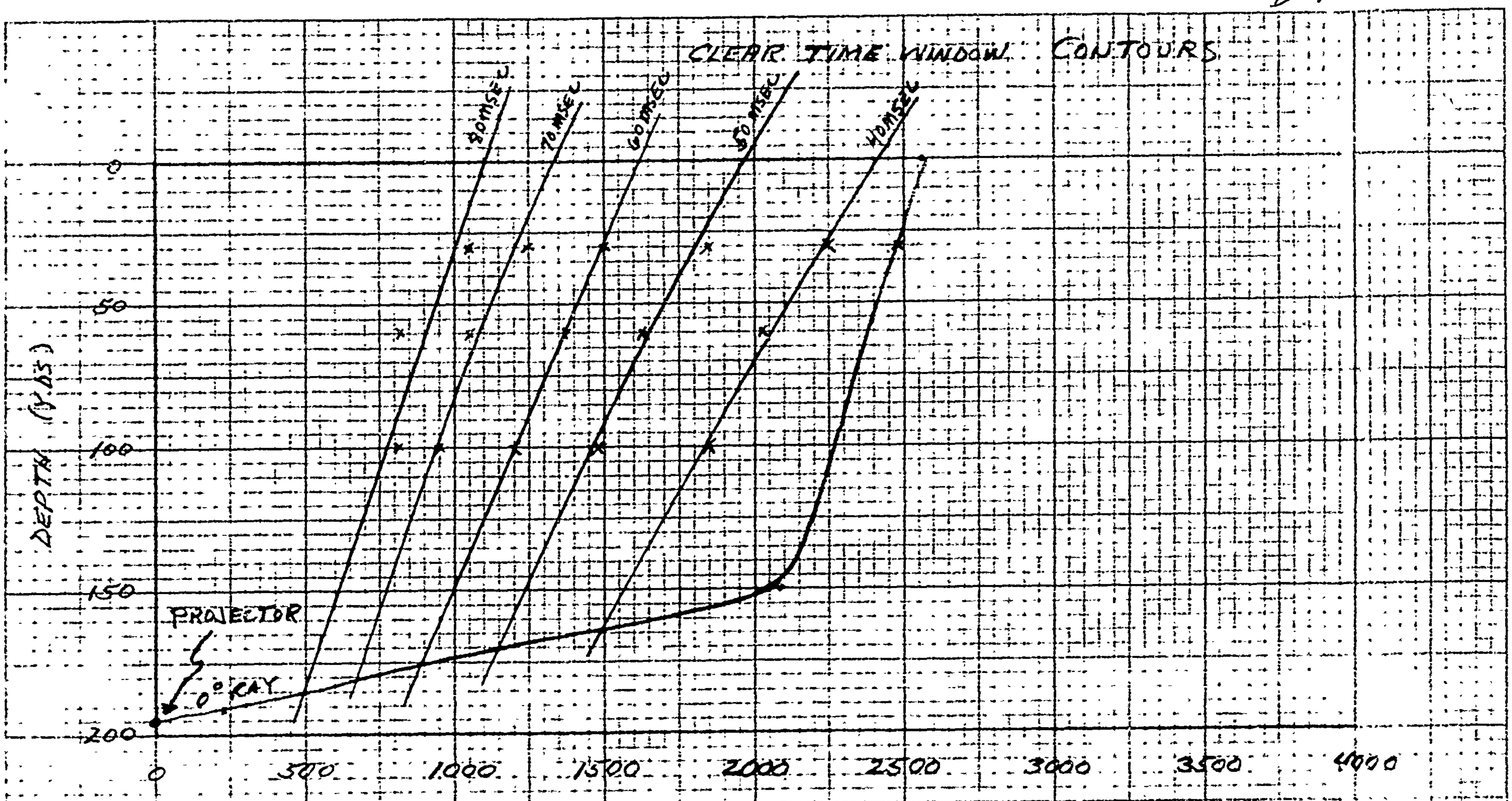


FIGURE 19.
DABOB BAY VELOCITY PROFILE D-7
MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS; DOWNWARD LOOKING HYDROPHONE

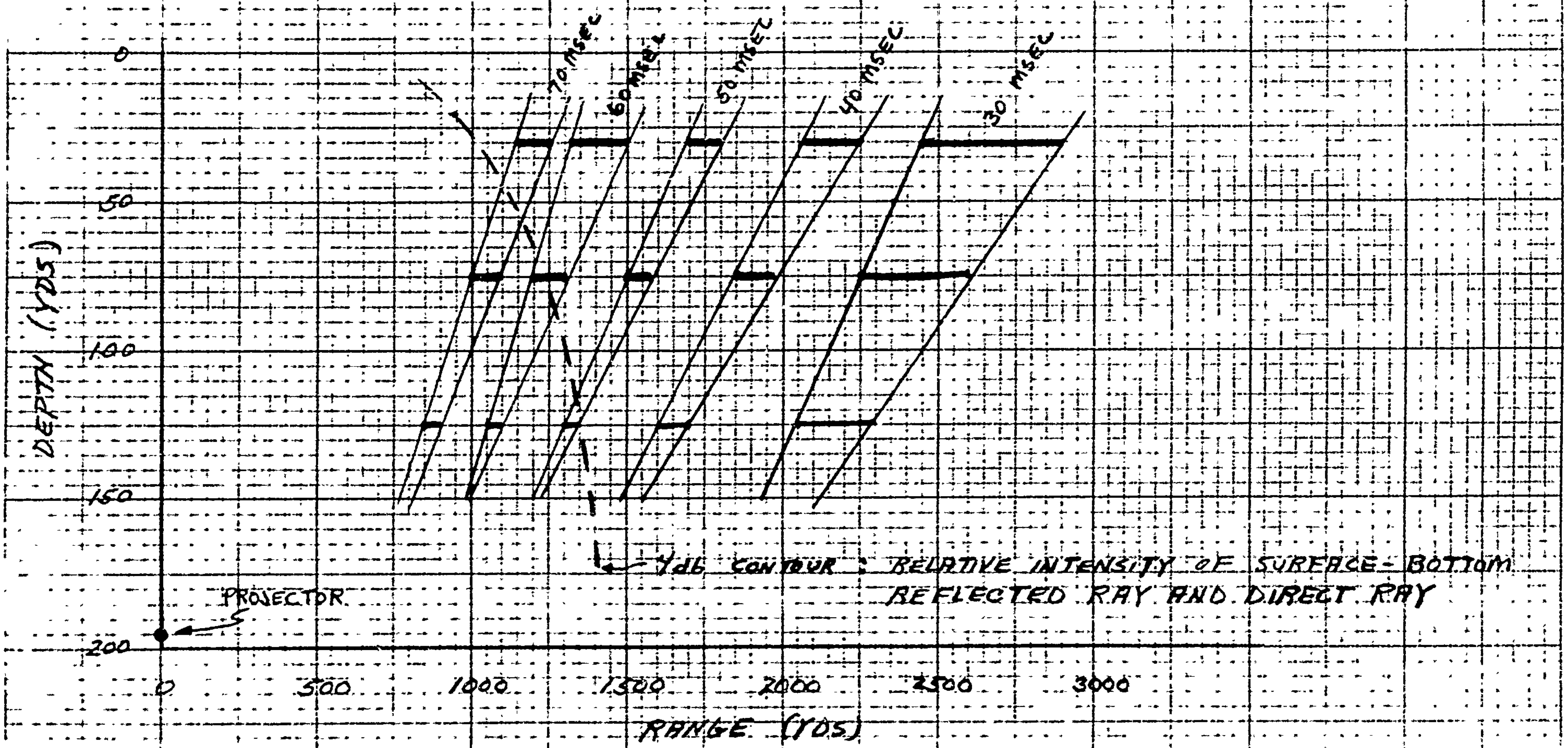


FIGURE 20. VARIATION OF CLEAR TIME WINDOWS IN DABOB BAY, BASED UPON VELOCITY PROFILES D-1, D-2, D-3, D-4, D-5, AND D-7

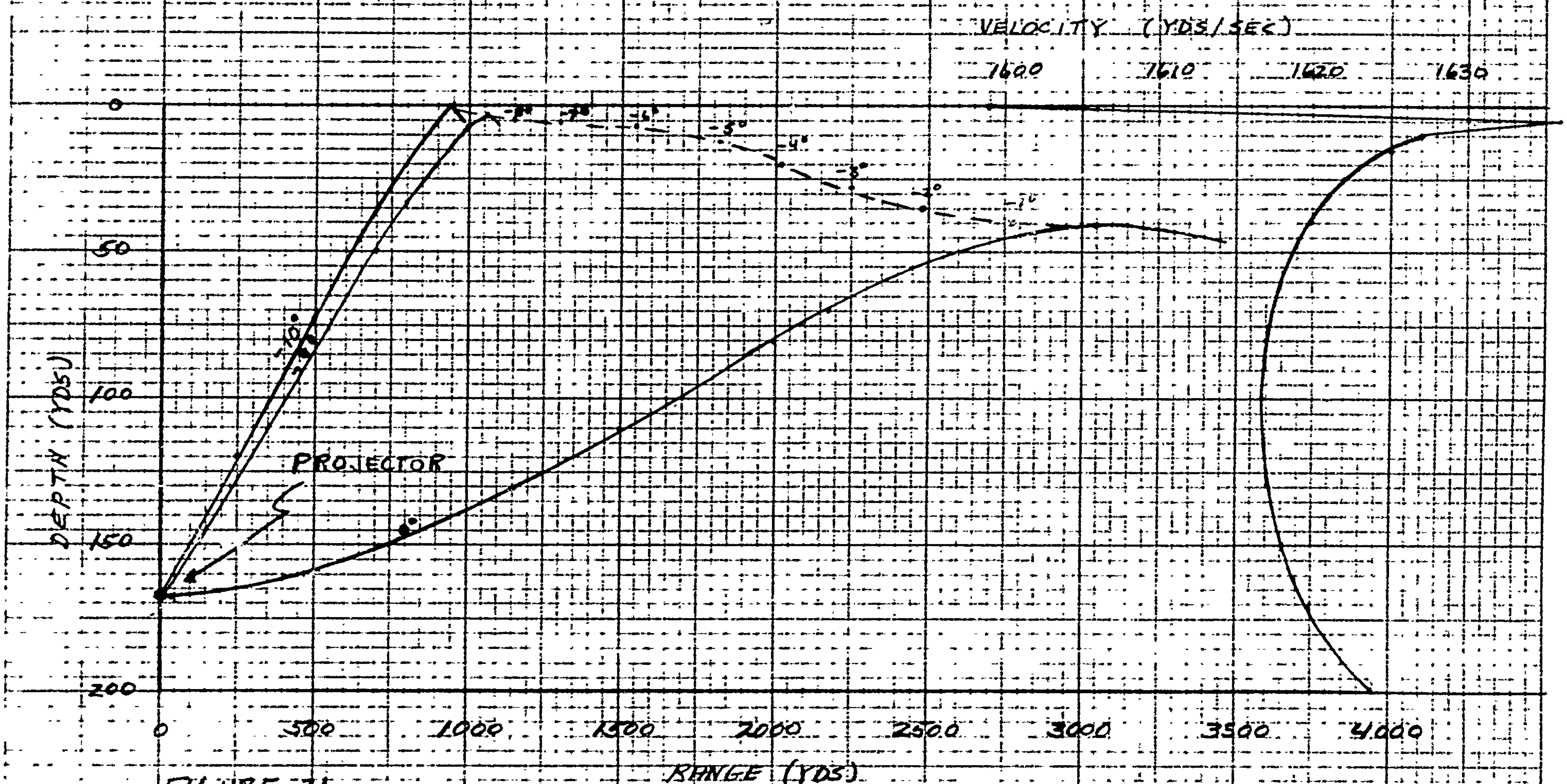


FIGURE 21.

DABOB BAY VELOCITY PROFILE D-1

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS;
DOWNWARD LOOKING HYDROPHONE

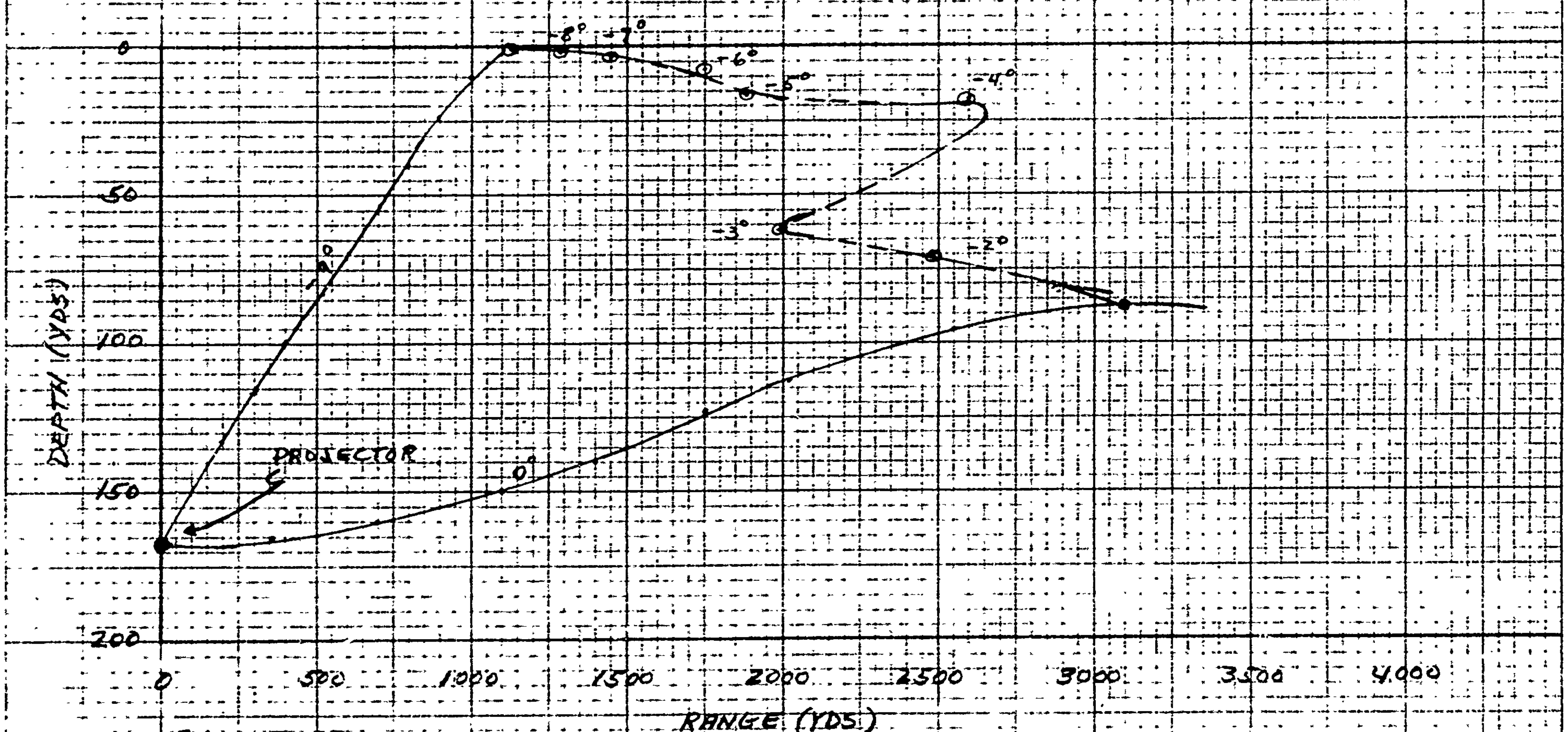


FIGURE 22.

DABOB BAY VELOCITY PROFILE D-2

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS; DOWNWARD LOOKING HYDROPHONE

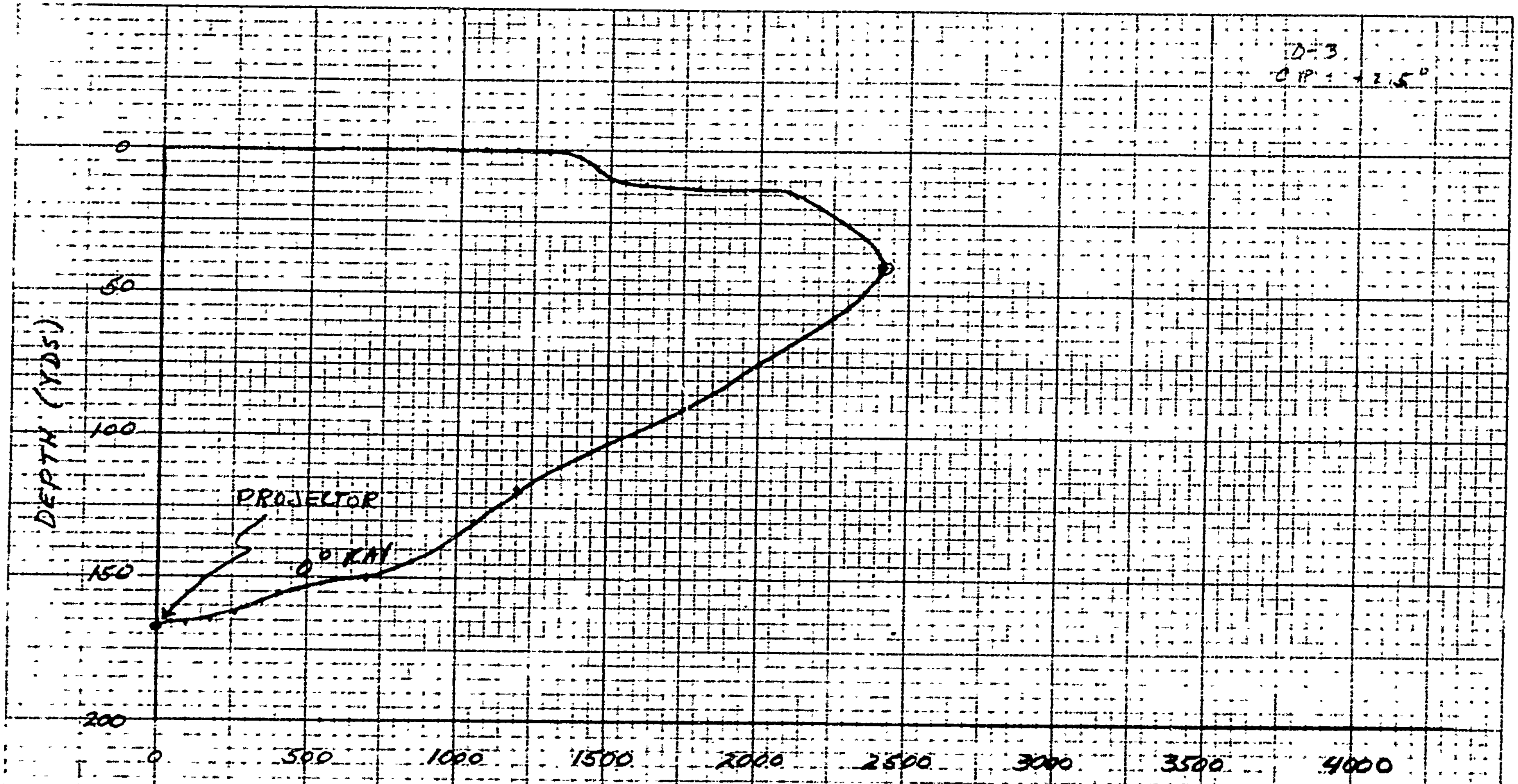


FIGURE 23.
DABOB BAY VELOCITY PROFILE D-3
MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS;
DOWNWARD LOOKING HYDROPHONE

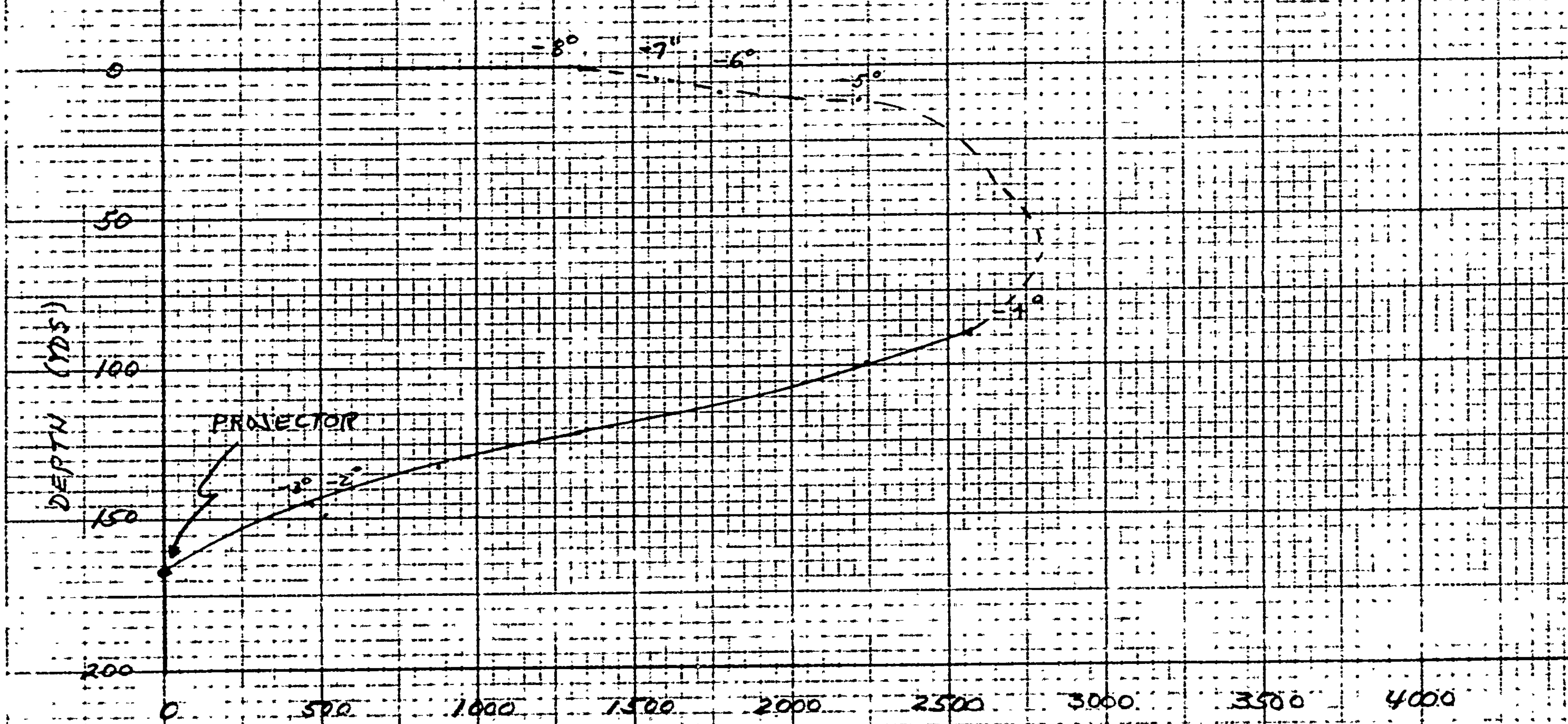


FIGURE 24.

DABOB BAY VELOCITY PROFILE D-4

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS; DOWNWARD LOOKING HYDROPHONE

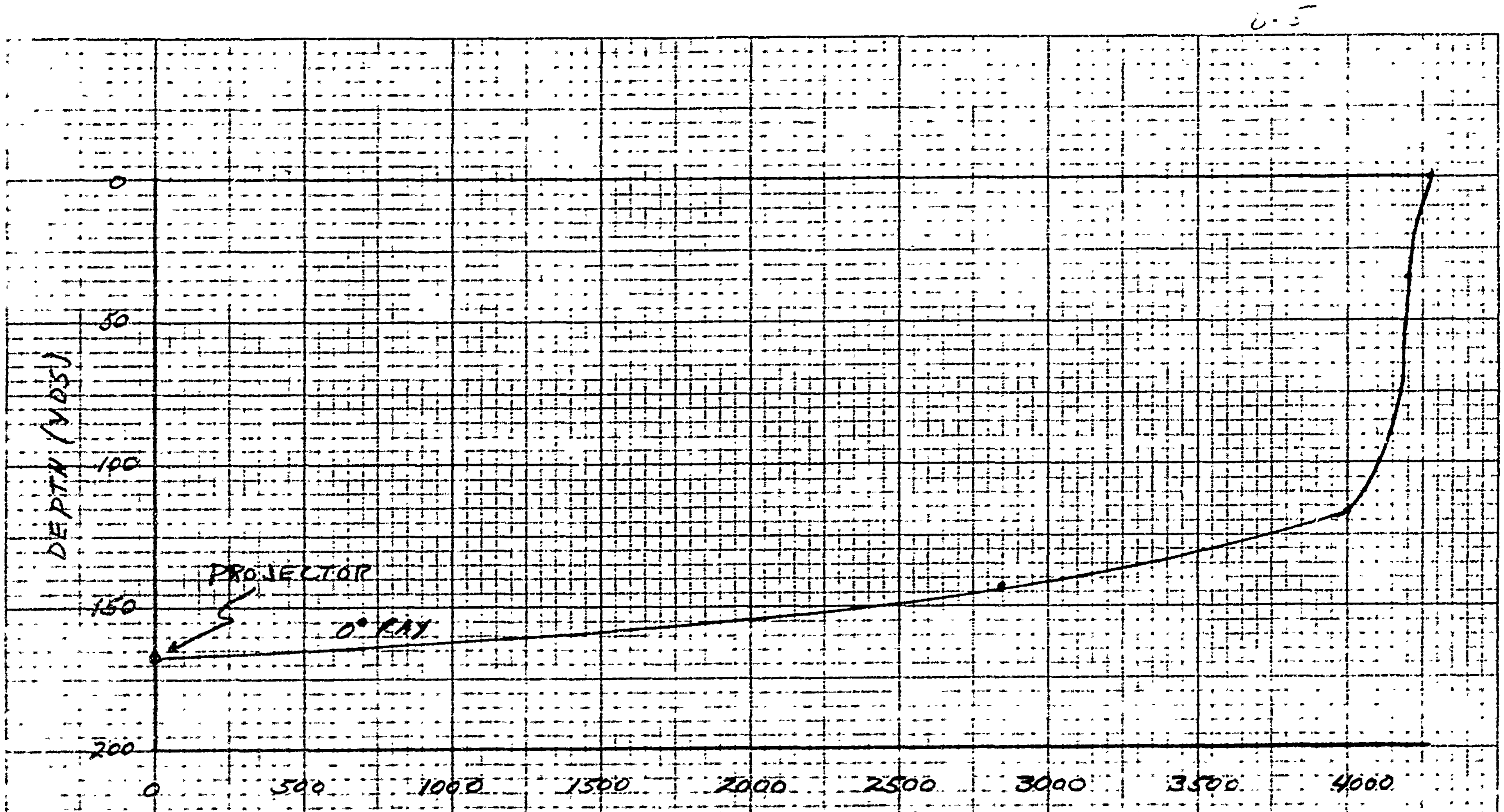


FIGURE 25.

DABOB BAY VELOCITY PROFILE D-5

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS; DOWNWARD LOOKING HYDROPHONE

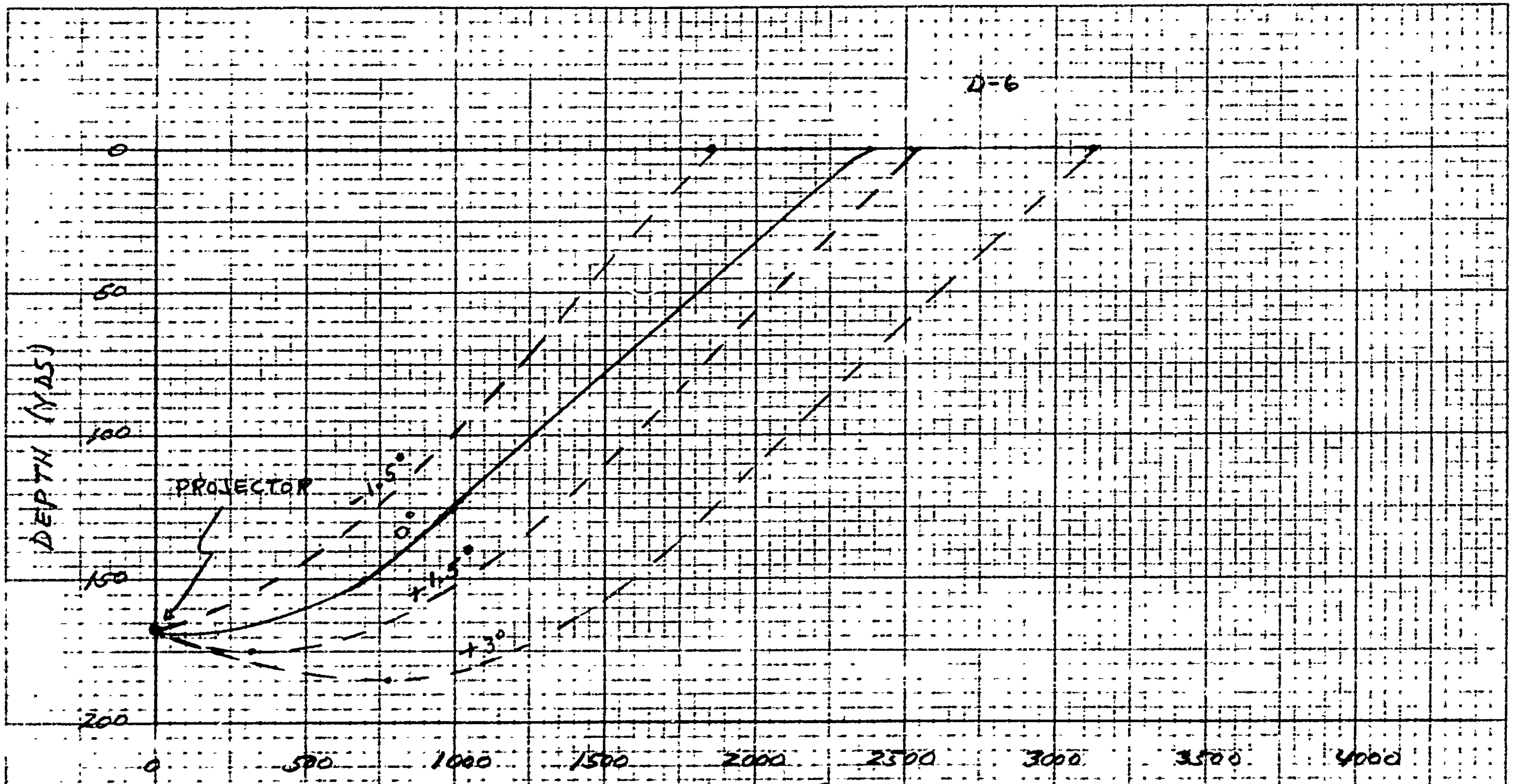


FIGURE 26

DABOB BAY VELOCITY PROFILE D-6

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS; DOWNWARD LOOKING HYDROPHONE

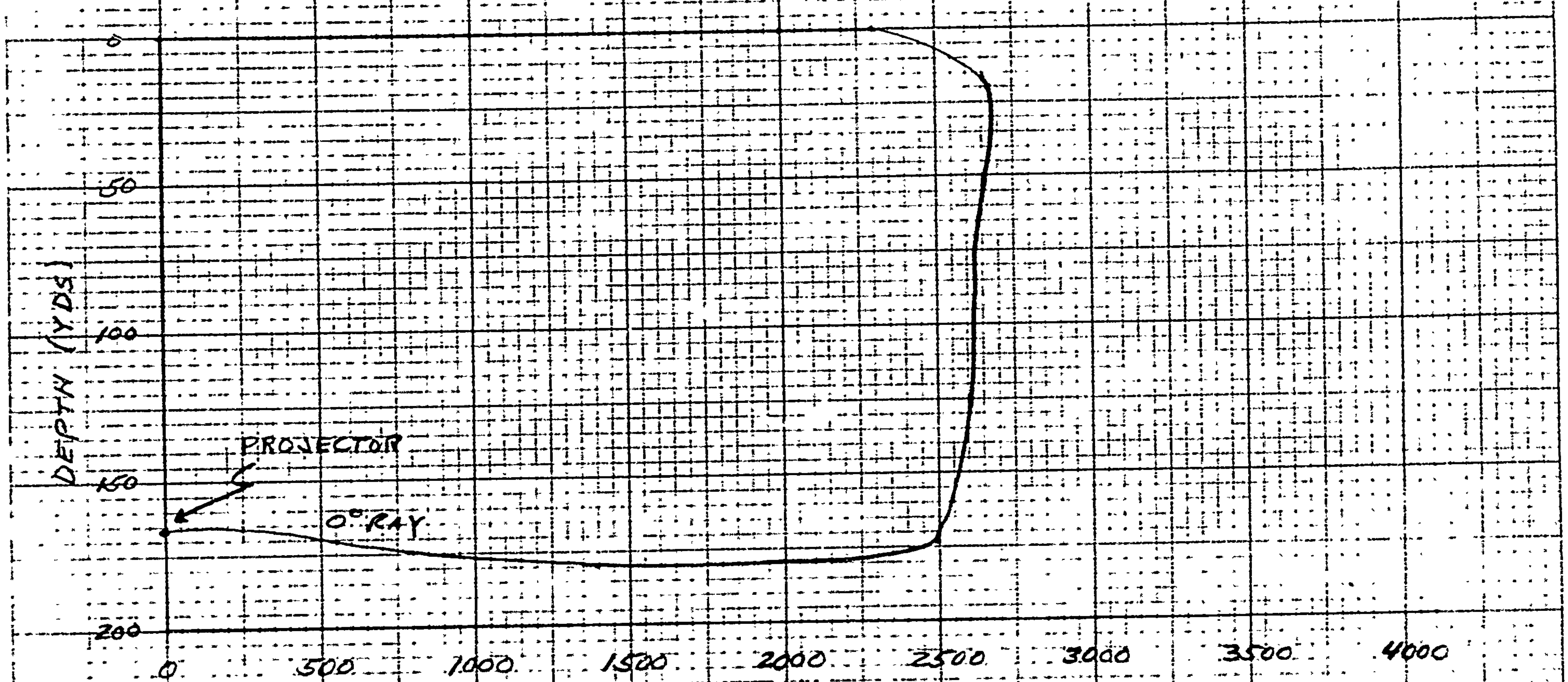


FIGURE 27

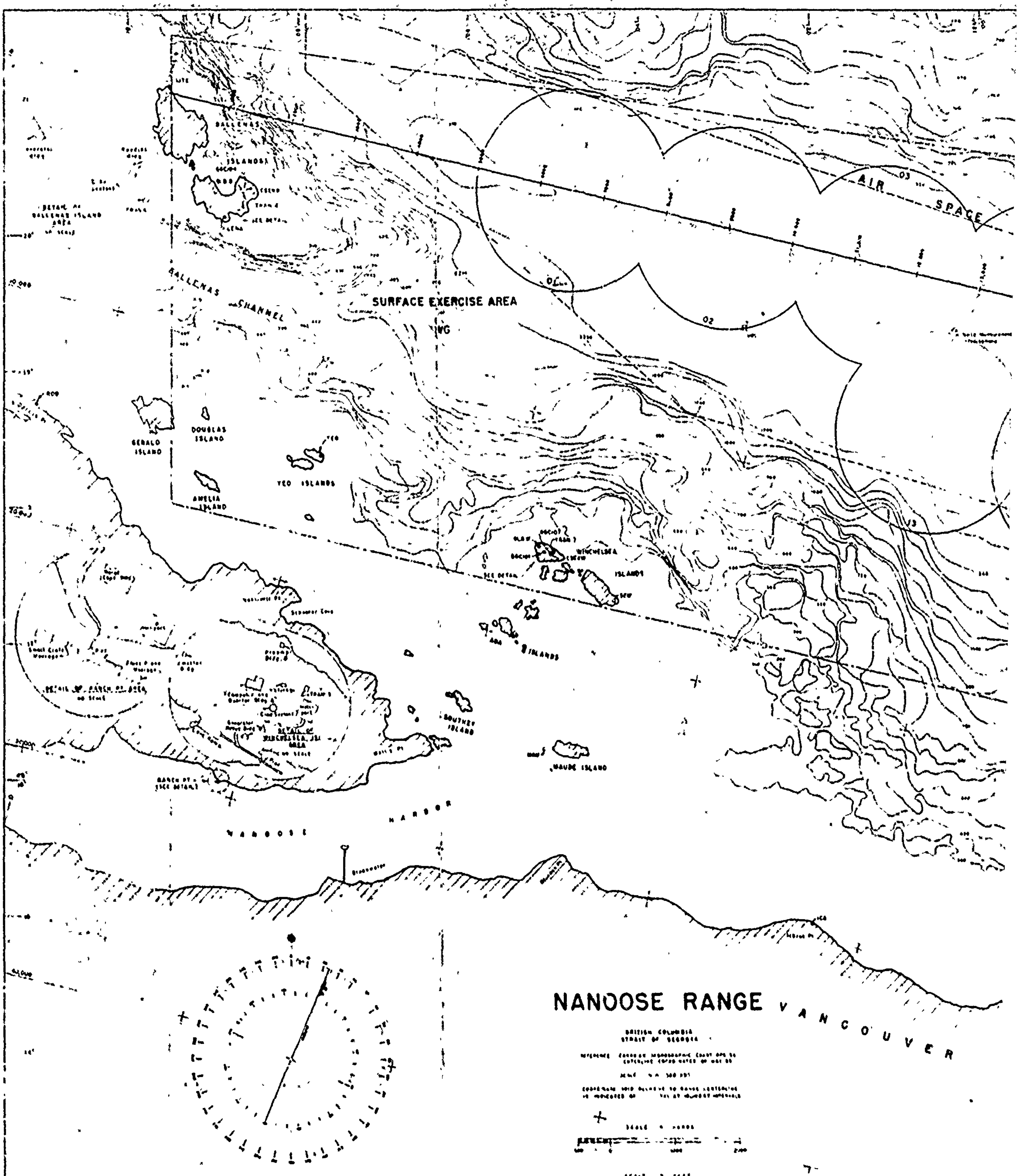
DABOB BAY VELOCITY PROFILE D-7

MAXIMUM RANGE COVERAGE VERSUS HYDROPHONE DEPTH; DIRECT RAYS;
DOWNWARD LOOKING HYDROPHONE

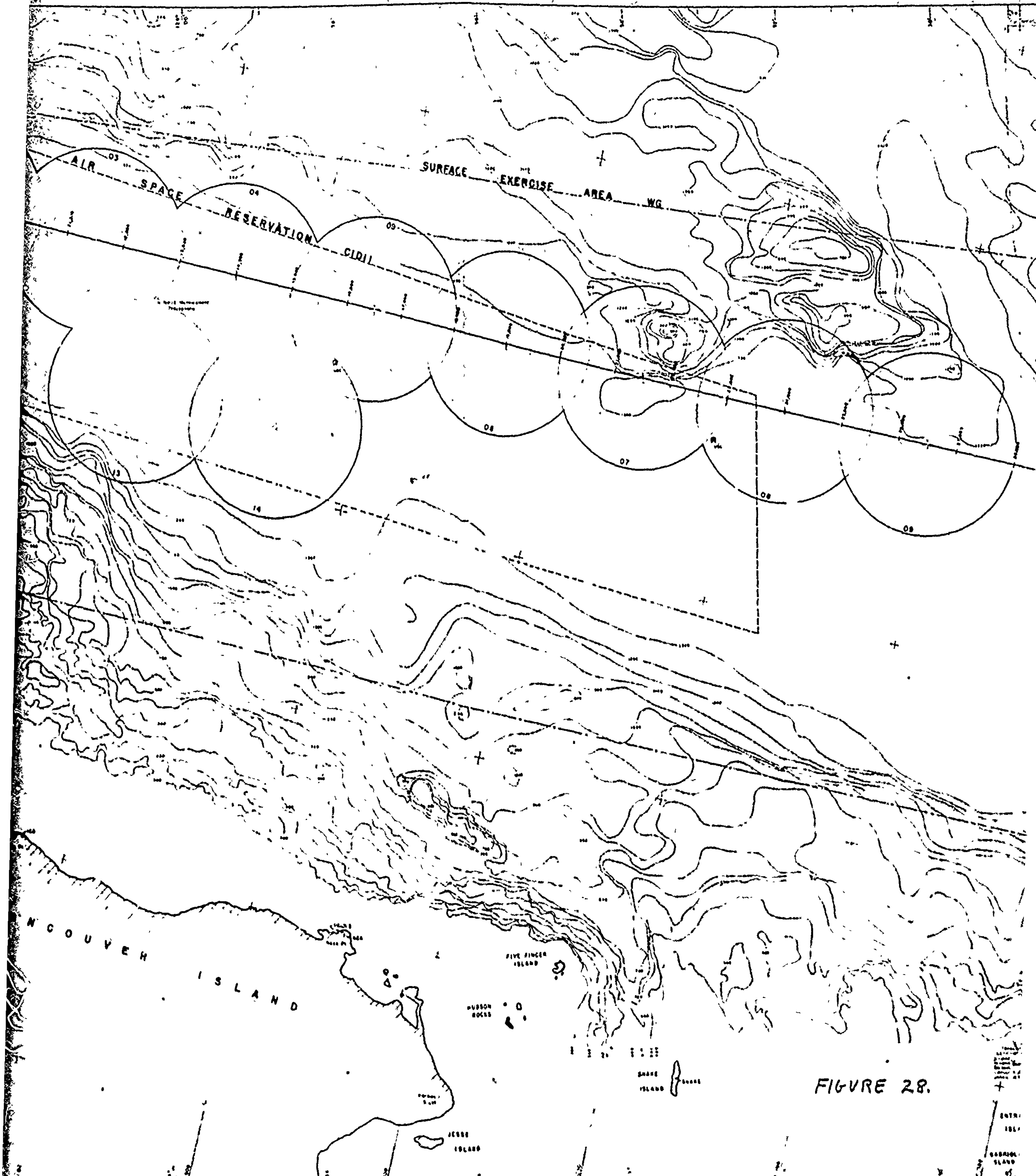
Table 2. Nanoose Bay Bottom Loss*

GRAZING ANGLE	BOTTOM LOSS
10°	14-15 db
30°	15-16 db
45°	12-13 db
60°	15-16 db

*NOTE: This data is an excerpt from a Bolt, Beraner and Newman, Inc. report. The title and date of the report are unknown.



SURFACE EXERCISE AREA
AIR SPACE
BALLENAS CHANNEL
BALLENAS ISLANDS
GERALD ISLAND
DOUGLAS ISLAND
YEO ISLANDS
AMELIA ISLAND
WINCHELSEA ISLANDS
SOUTHEY ISLAND
MAUDE ISLAND
NANOOSE HARBOR
NANOOSE RANGE
VANCOUVER
BRITISH COLUMBIA
STRAIT OF GEORGIA
DEPTH IN FEET AT MLLW



AIR SPACE RESERVATION CIDII
SURFACE EXERCISE AREA WG
VANCOUVER ISLAND
FIVE FINGER ISLAND
HUDSON ROCKS
SNAKE ISLAND
JESSE ISLAND

FIGURE 28.

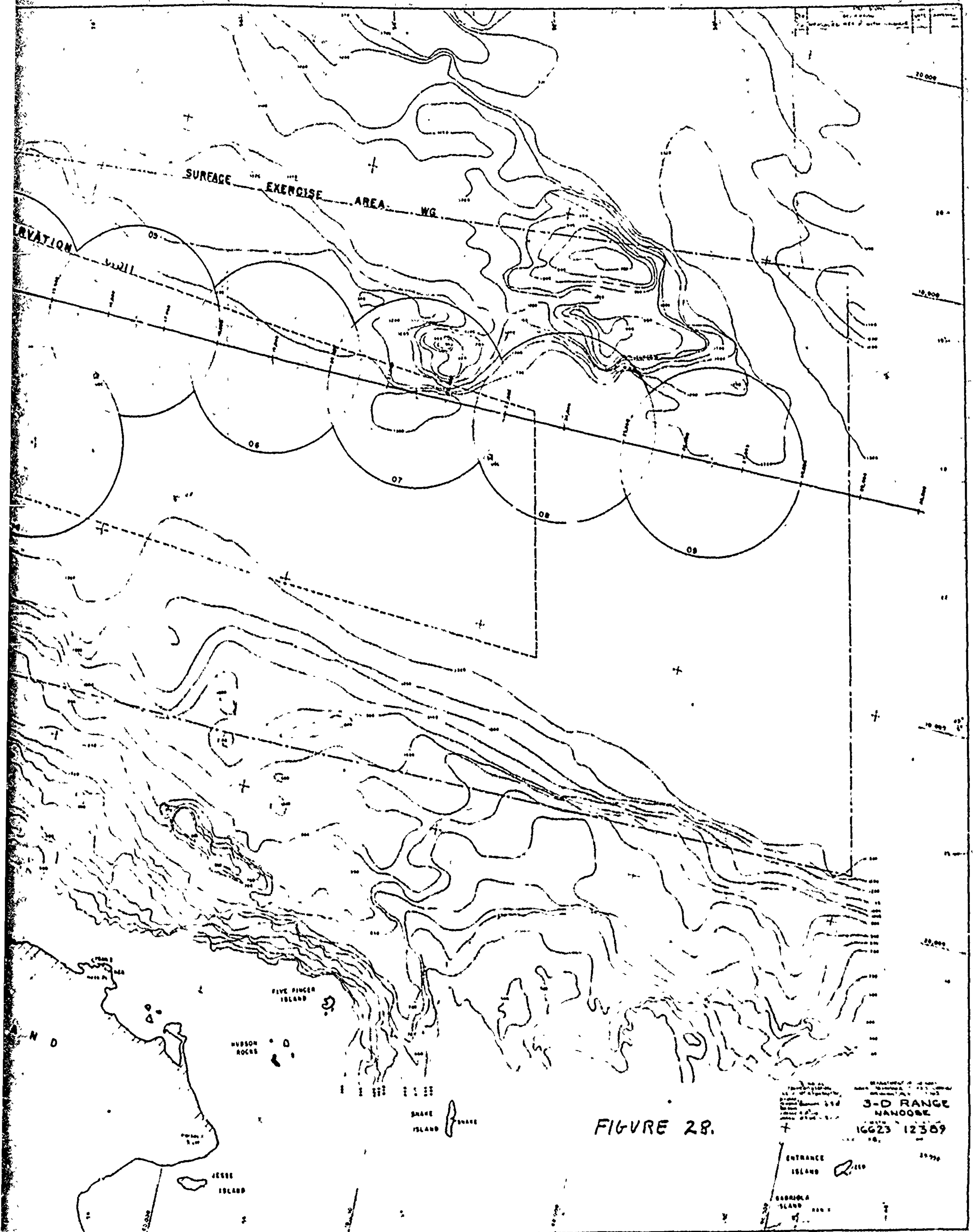
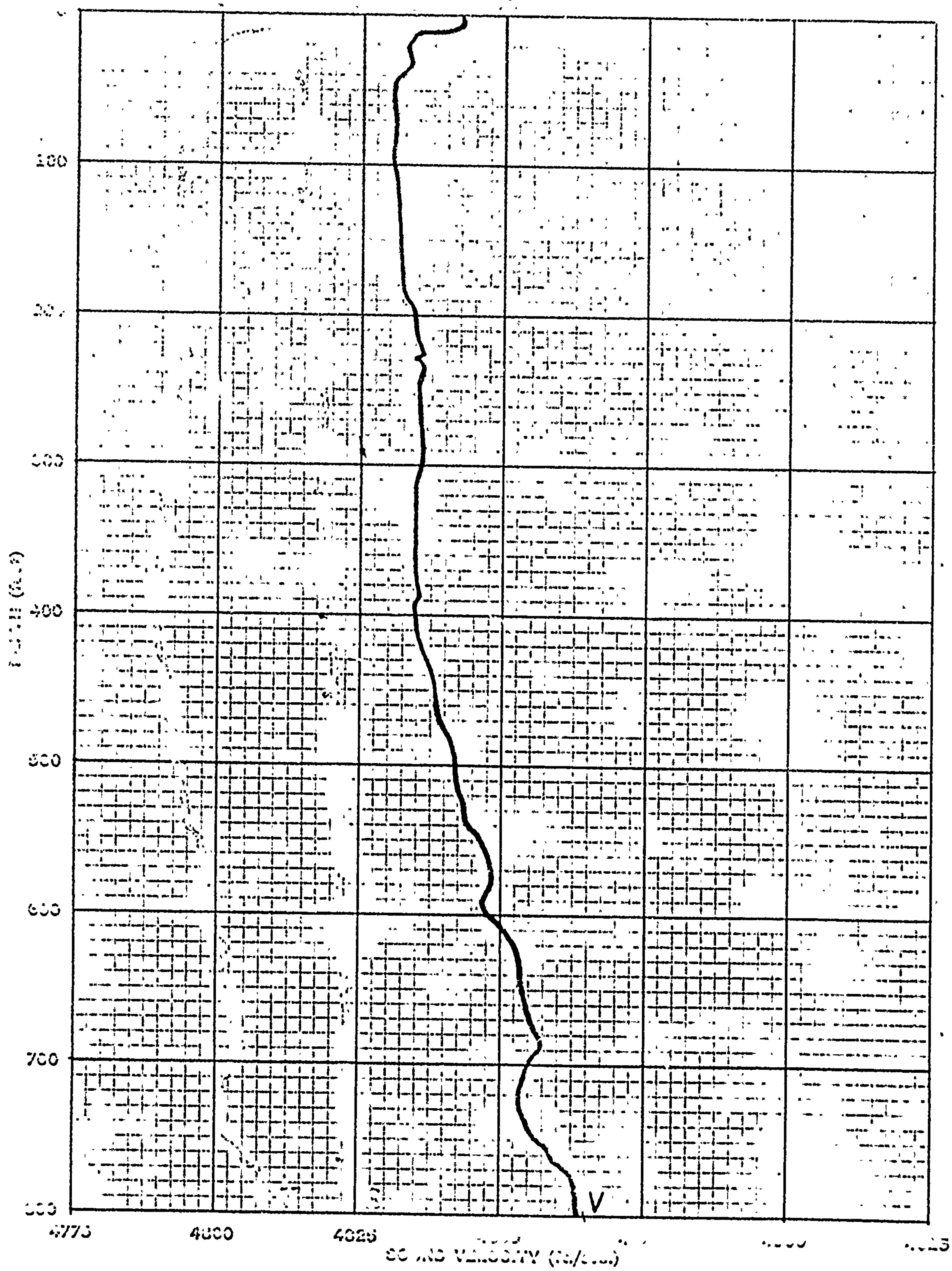

SURFACE EXERCISE AREA WG
06
07
08
09
FIVE FINGER ISLAND
HUDSON ROCKS
SNAKE ISLAND
JESSE ISLAND
ENTRANCE ISLAND
GABRIOLA ISLAND
3-D RANGE
NANOOSE
16623 12389

FIGURE 28.



RANGE: *NANOOSE* DATE: *4-15-69 0645* ... *14771, 71S*

FIG. VELOCITY/TEMPERATURE PROFILE

FIGURE 29. NANOOSE BAY VELOCITY PROFILE N-1

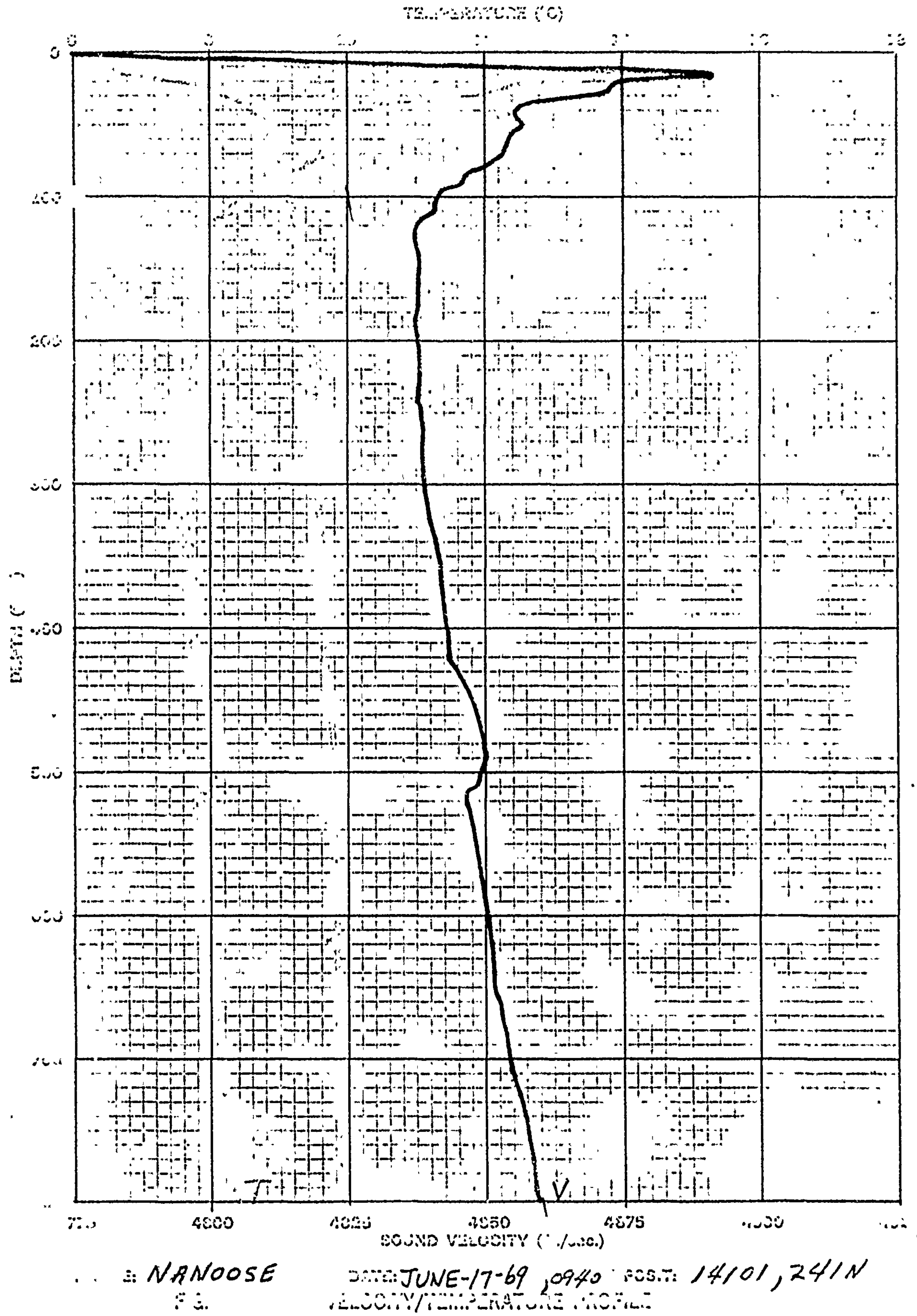
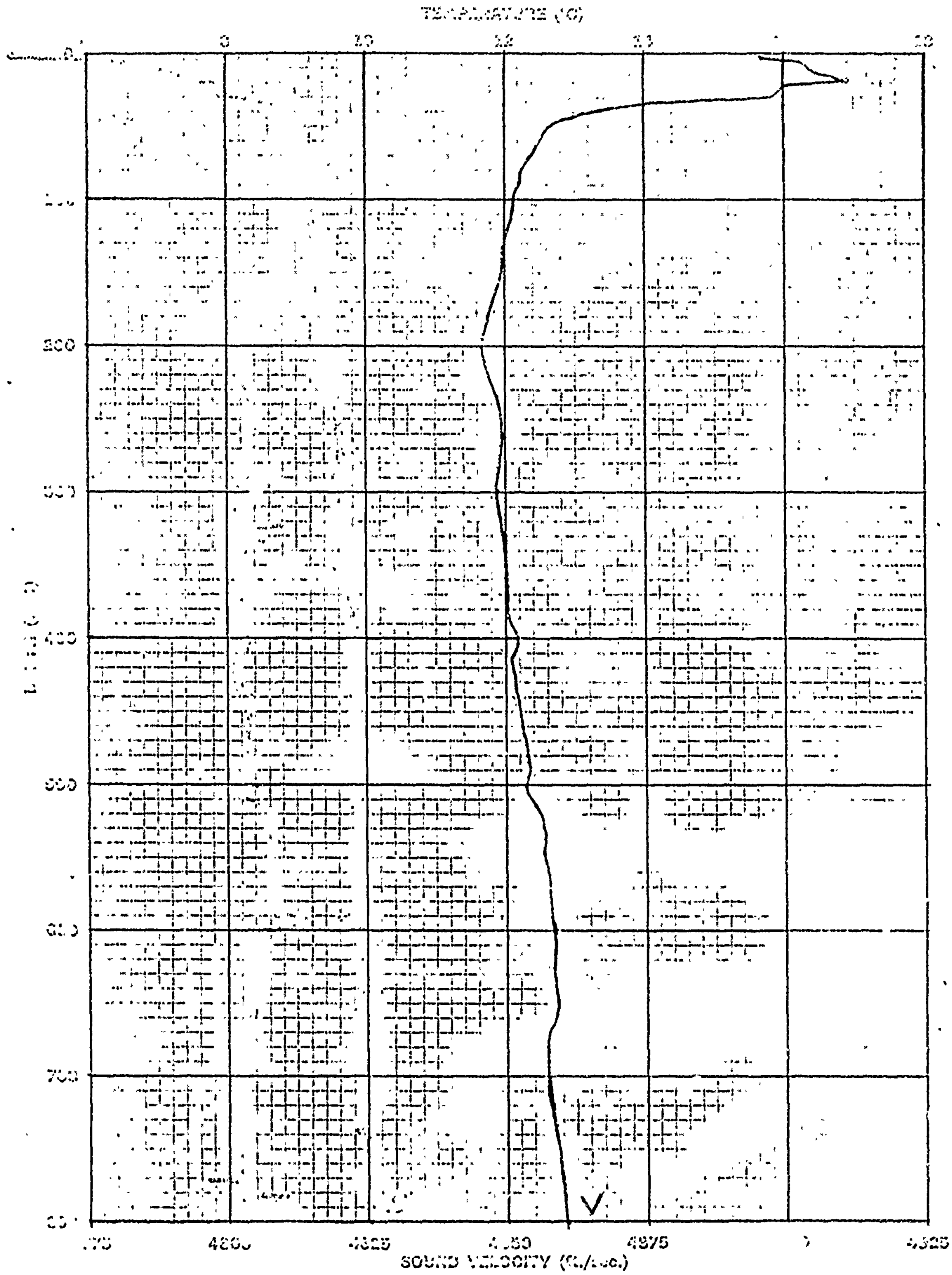


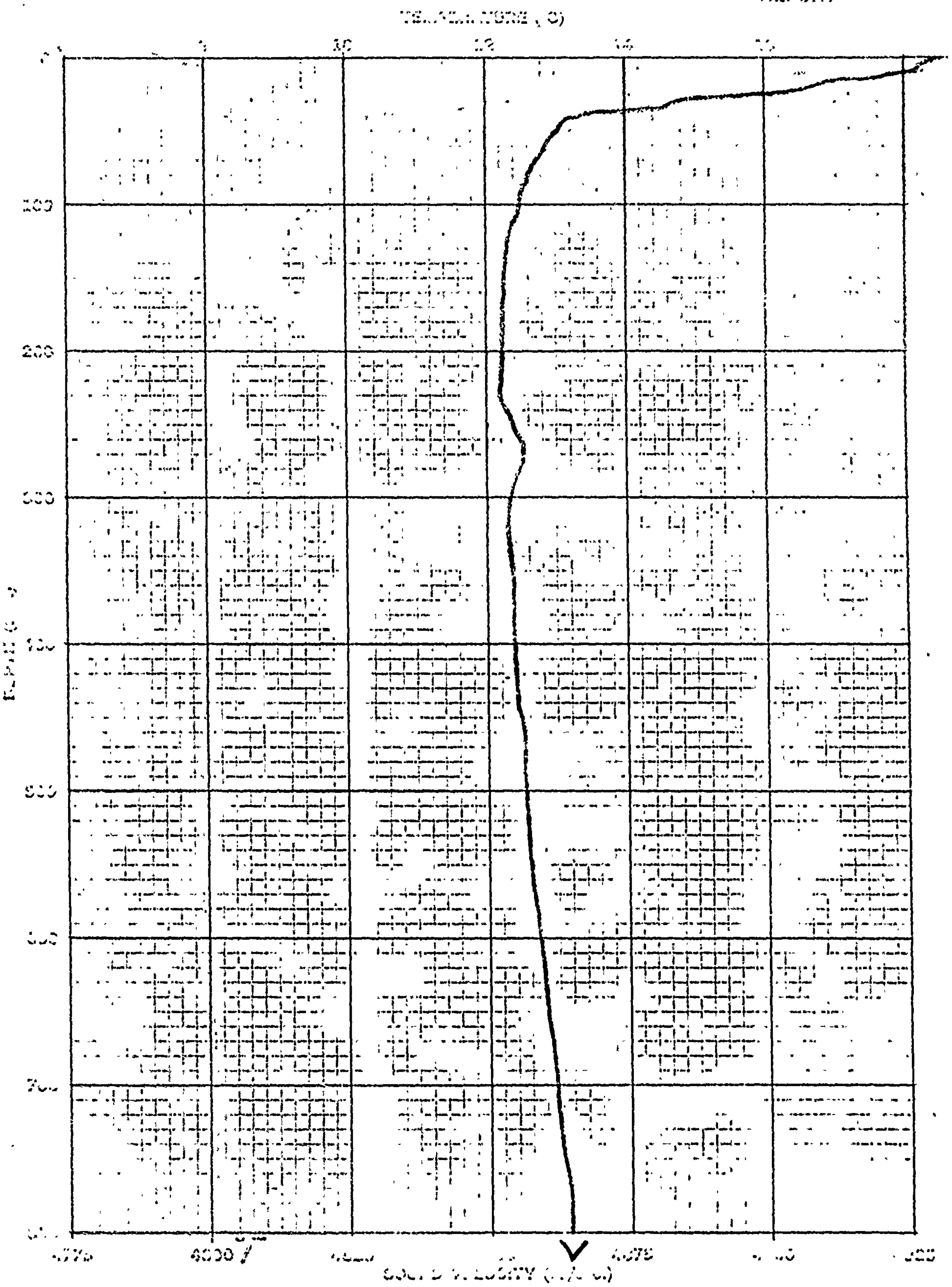
FIGURE 30. NANOOSE BAY VELOCITY PROFILE N-2



NANOOSE 06AUG69 10:04 14100, 471N

FIG. VELOCITY/TE...

FIGURE 31. NANOOSE BAY VELOCITY PROFILE N-3



NANOOSE DATE 8-1-69 1055 10000, 21N

FIG. VELOCITY/TEMPERATURE

FIGURE 32. NANOOSE BAY VELOCITY PROFILE N-4

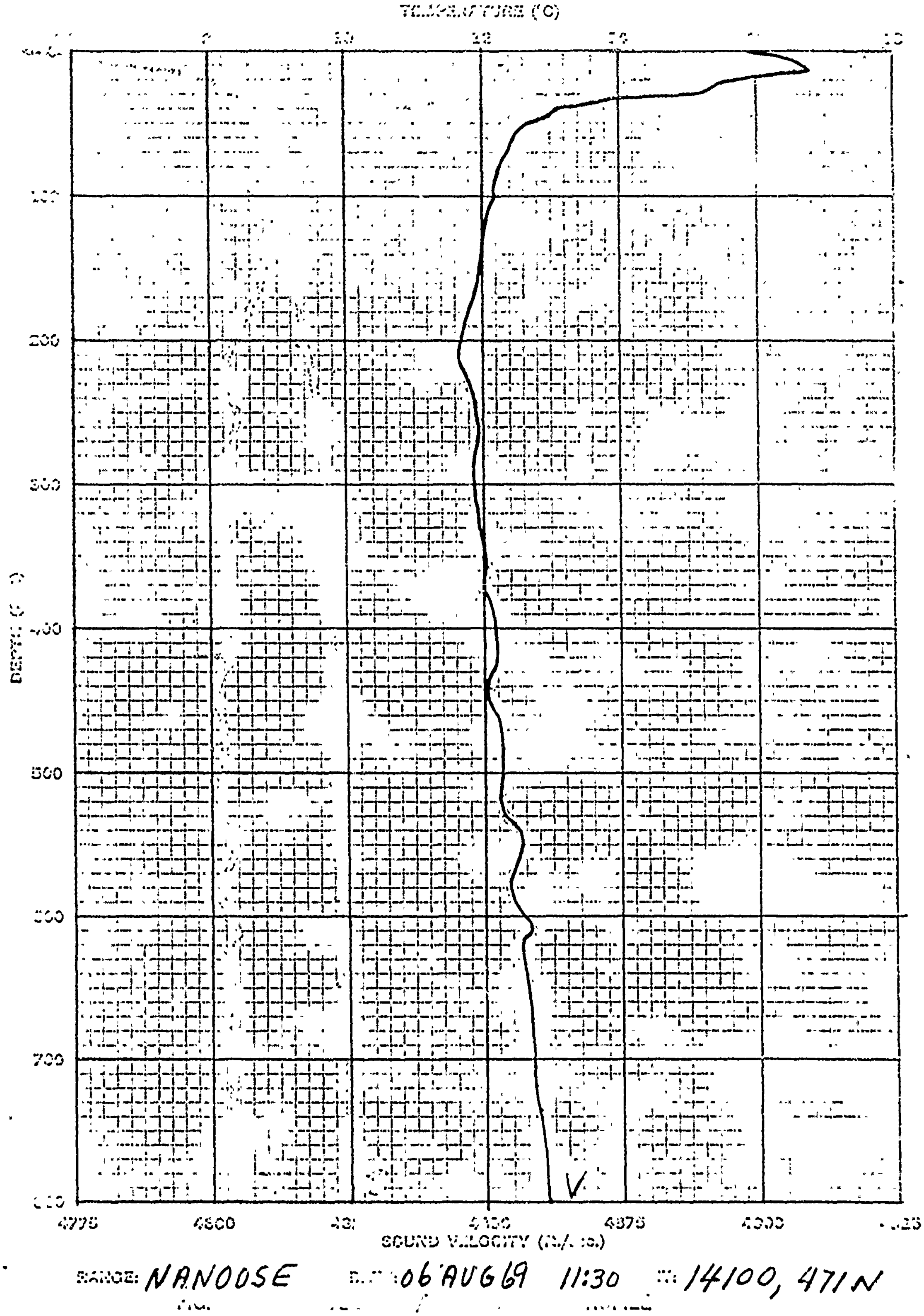
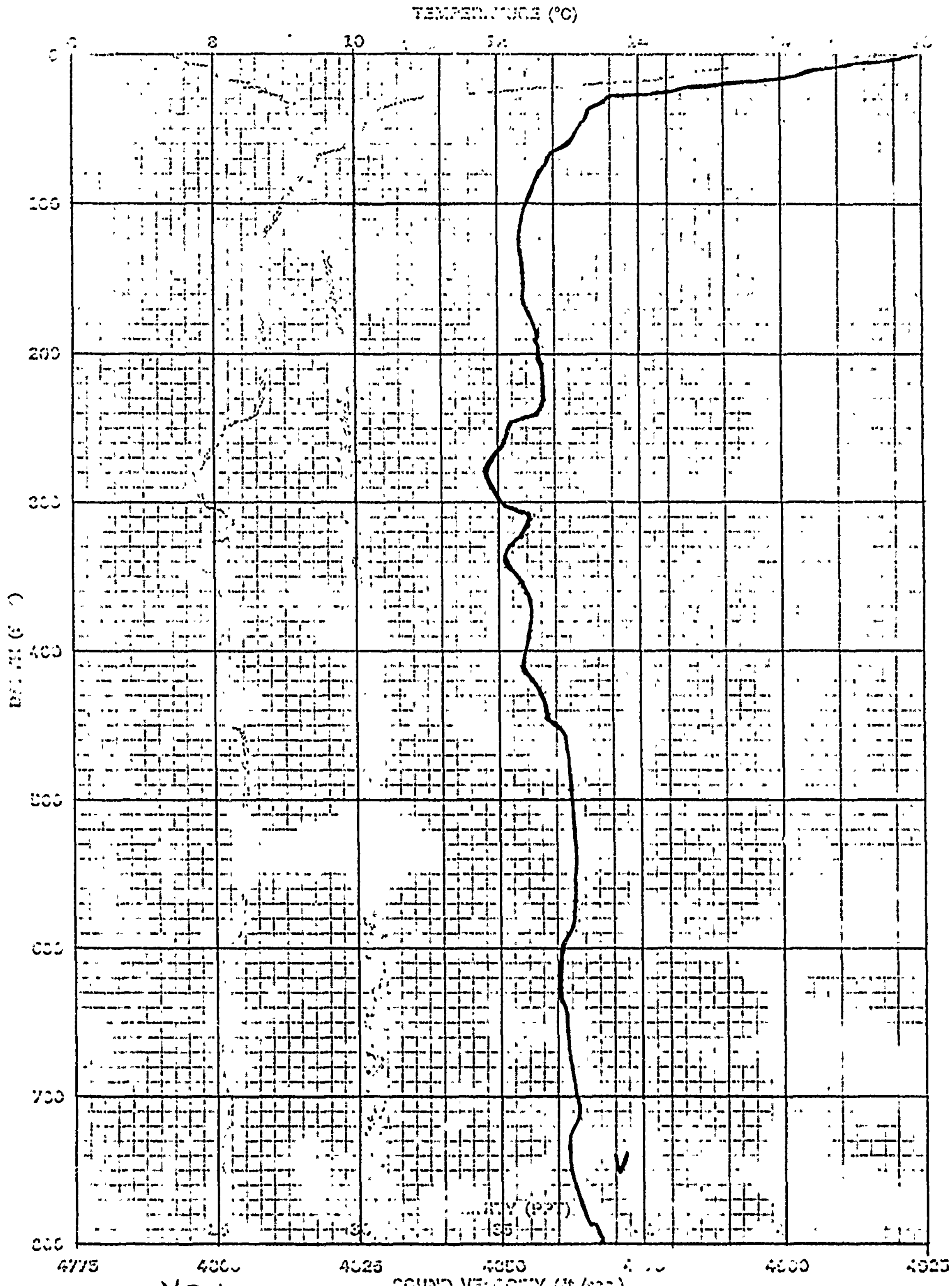


FIGURE 33. NANOOSE BAY VELOCITY PROFILE N-5

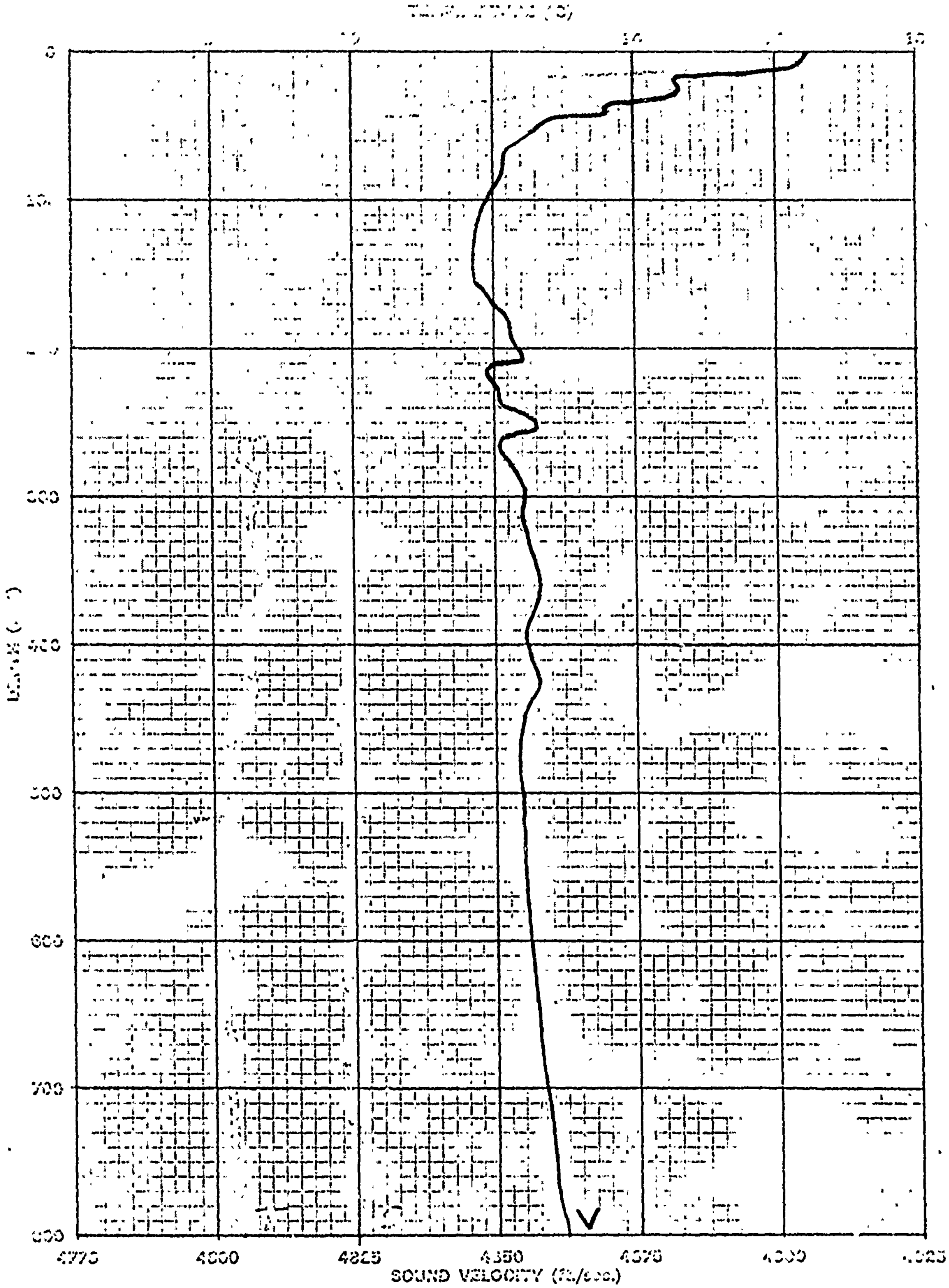


RANGE: NANOOSE DATE: 8-1-69 14100

FIG. VELOCITY/TEMPERATURE PROFILE

FIGURE 34. NANOOSE BAY VELOCITY PROFILE 1435
N-6

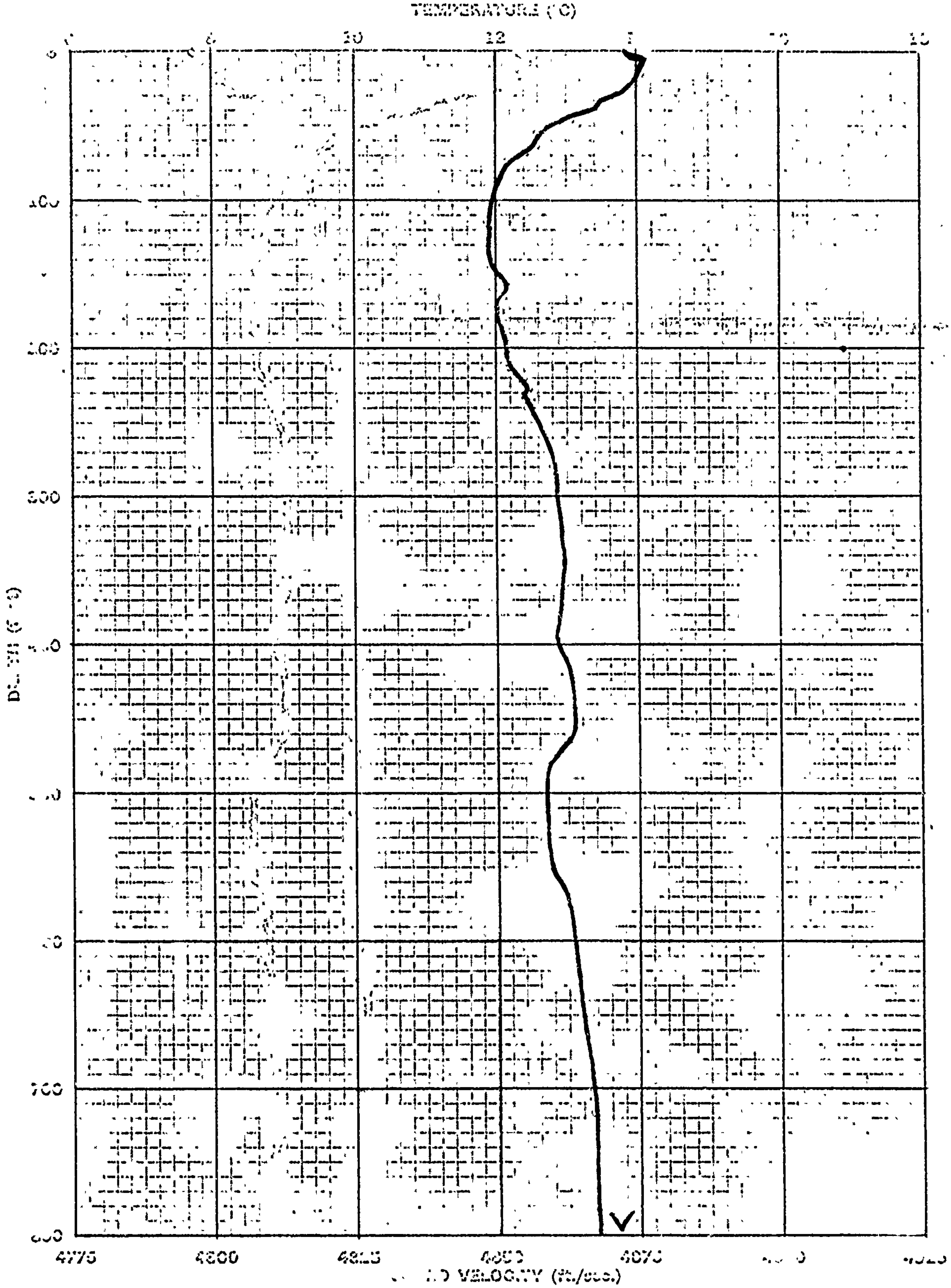
REPORT



RANGE: NANOOSE DATE: 25AUG69 13:10 POSIT: 14350, 1100S
FIG. VELOCITY/TEMPERATURE PROFILE

FIGURE 35. NANOOSE BAY VELOCITY PROFILE N-7

REPORT



RANGE: NANOOSE 06 OCT 69 POINT: 13800, 400N

FIGURE 36. NANOOSE BAY VELOCITY PROFILE N-8

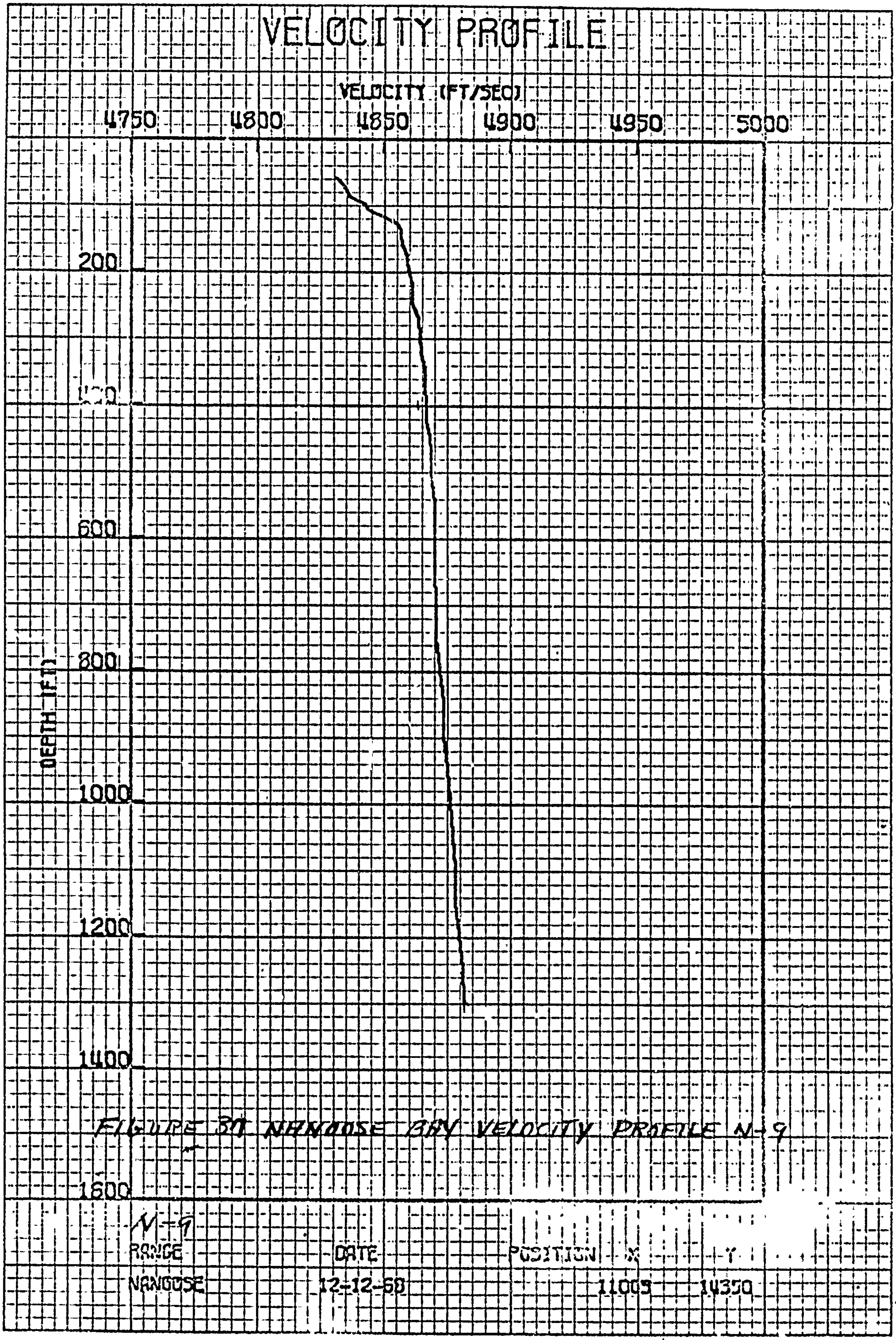


FIGURE 30 NANOOSE BAY VELOCITY PROFILE N-9

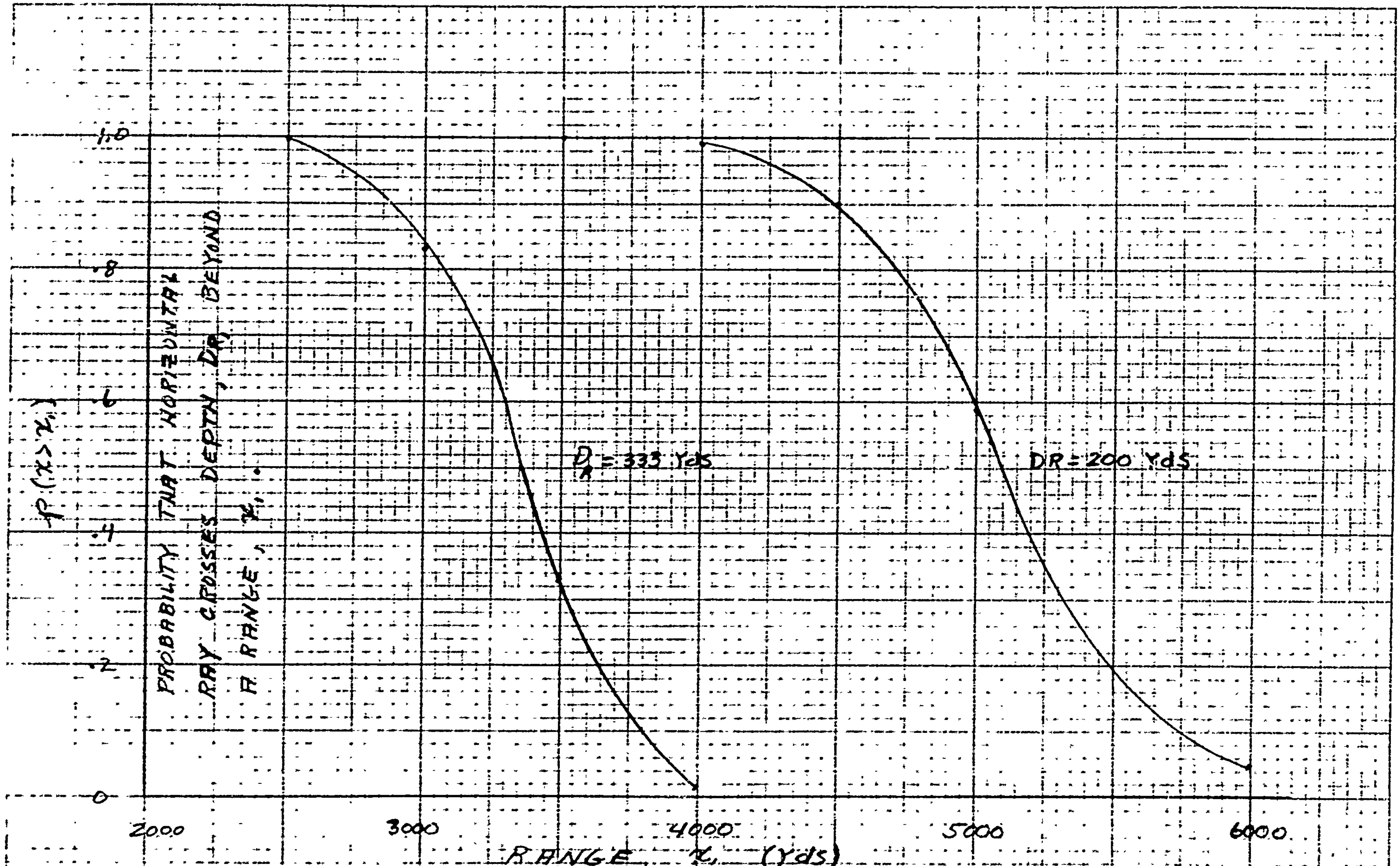


FIGURE 38. DISTRIBUTION FUNCTION FOR HORIZONTAL RAY CROSSING THE 333 Yd AND 200 YD DEPTHS FOR A PROJECTOR MOUNTED 4 Yds FROM THE BOTTOM IN NANOOSE BAY.

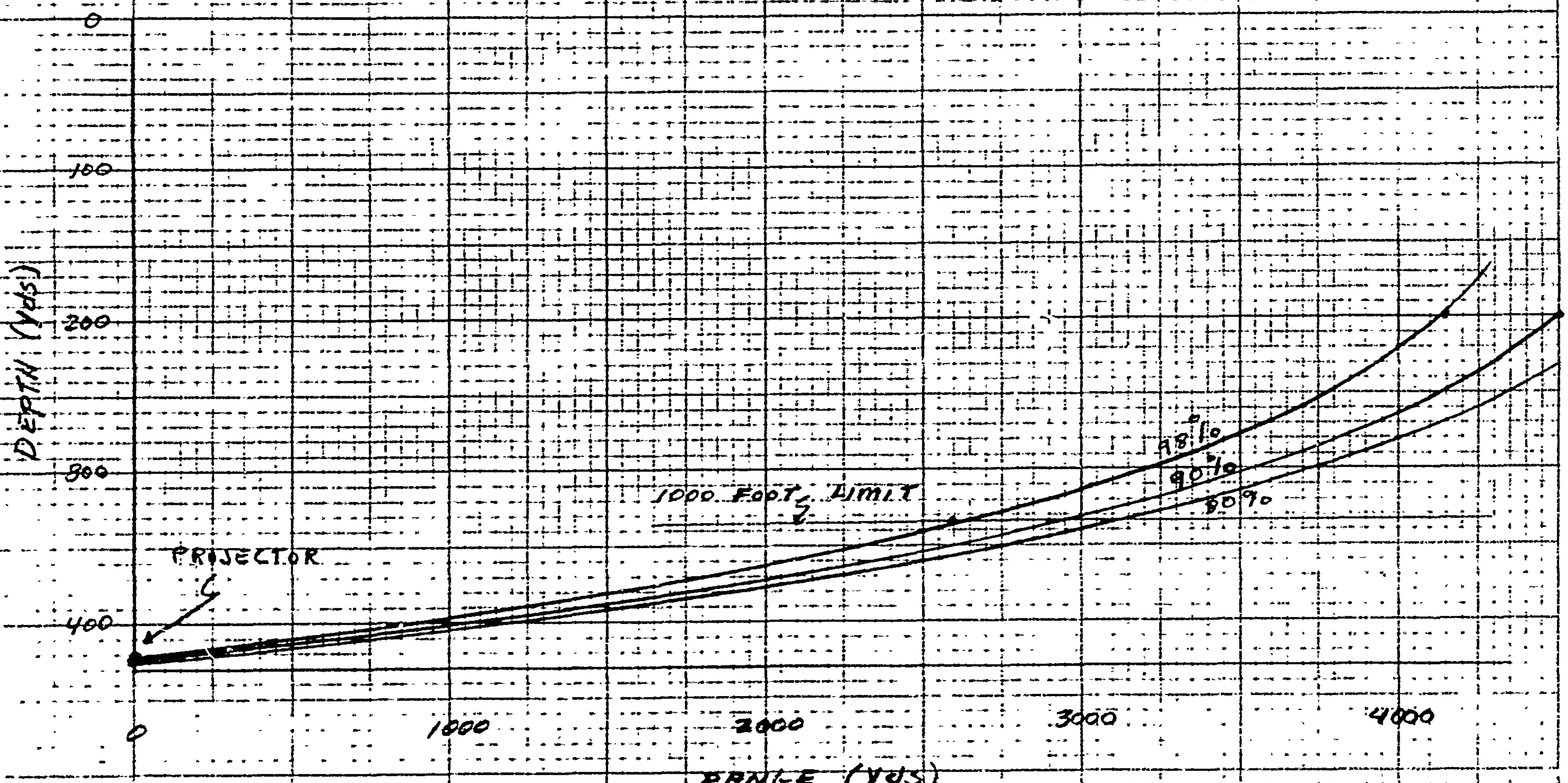


FIGURE 39. CONTOURS OF COVERAGE OF VARIOUS CONFIDENCE LEVELS FOR PROJECTORS MOUNTED 4 YDS FROM THE BOTTOM IN NANOOSE BAY

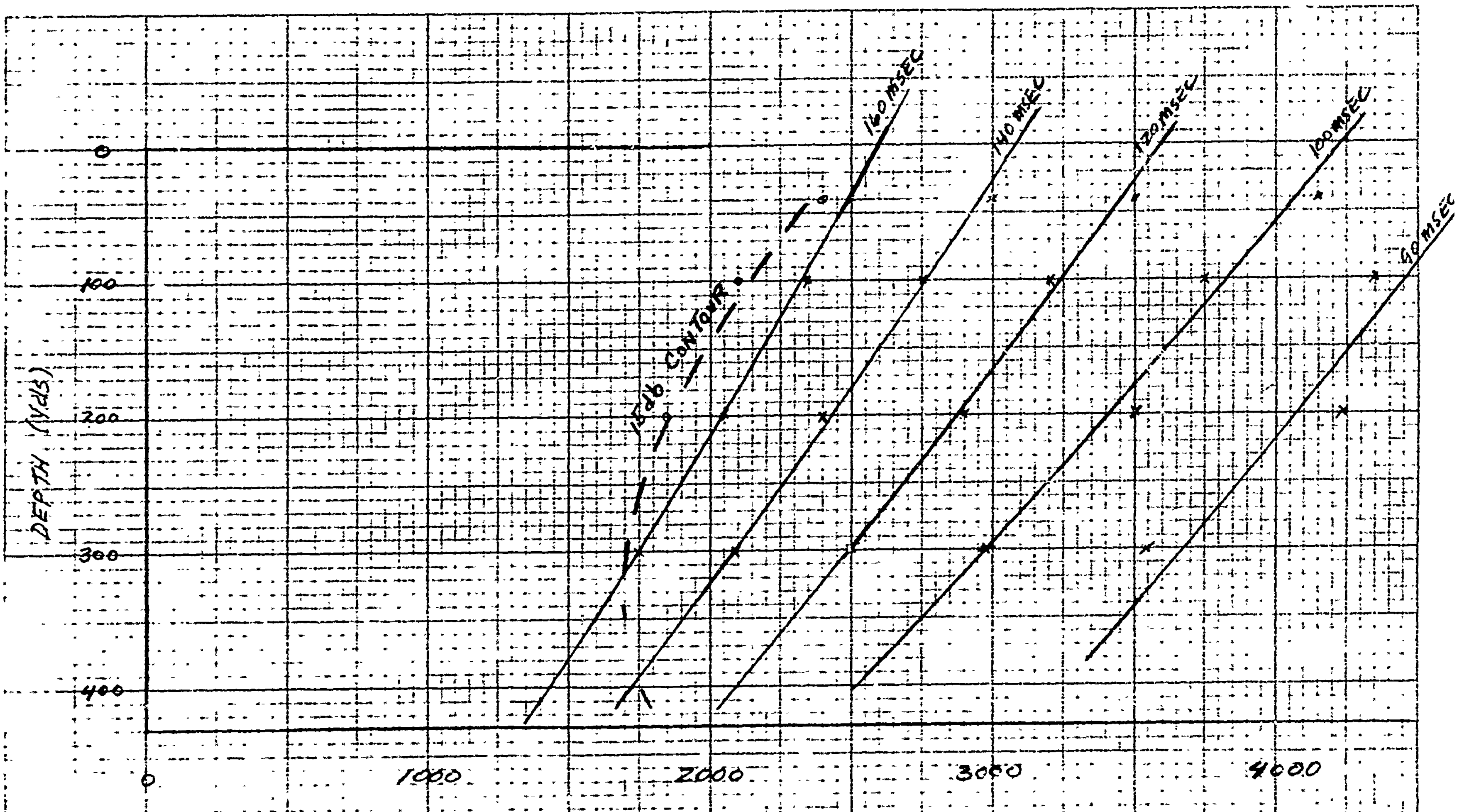


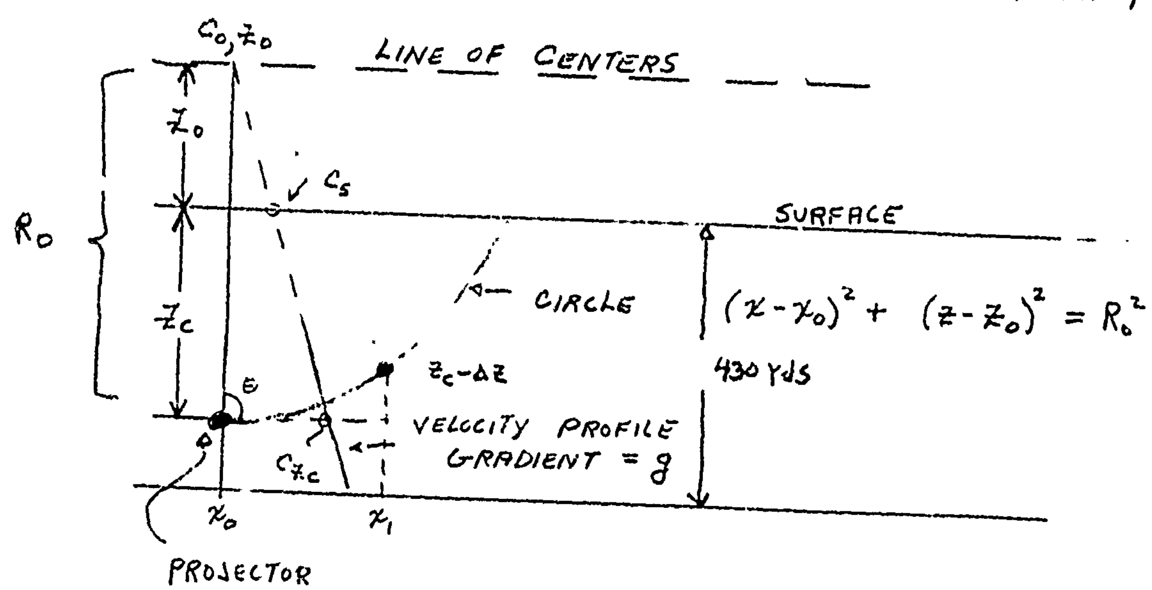
FIGURE 40. CLEAR TIME WINDOWS IN NANOOSE BAY BASED UPON VELOCITY PROFILE N-4.

APPENDIX A.

ANALYSIS OF NANOOSE BAY VELOCITY PROFILES

PROFILE NO.	GRADIENT AT 600 TO 300 FEET (Yds/sec-Yd)
N-1	.0670
N-2	.0570
N-3	.0250
N-4	.0280
N-5	.0284
N-6	.0350
N-7	.0314
N-8	.0220
N-9	.0210

CONSTANT GRADIENT RAY TRACE ANALYSIS



$$C_{Z_c} = C_s + g Z_c$$

$$C_Z = C_{Z_c} + g (Z - Z_c)$$

$$C_{Z_0} = 0 = C_{Z_c} + g Z_0 - g Z_c = C_s + g Z_0$$

$$Z_0 = - \frac{C_s}{g}$$

FOR $\theta = 90°$ (HORIZONTAL RAY)

$$R_0 = [z_c - z_0]$$

$$(x-x_0)^2 + (z-z_0)^2 = R_0^2$$

FIND x_1 WHERE $z = z_c - \Delta z$

$$(x_1 - x_0)^2 + [(z_c - \Delta z) - z_0]^2 = [z_c - z_0]^2$$

$$x_0 = 0$$

$$x_1^2 = z_c^2 - 2z_c z_0 + z_0^2 - (z_c - \Delta z)^2 + 2z_0(z_c - \Delta z) - z_0^2$$

$$= z_c^2 - 2z_c z_0 + z_0^2 - z_c^2 + 2z_c\Delta z - \Delta z^2 + 2z_0 z_c - 2z_0\Delta z - z_0^2$$

$$= 2\Delta z\, z_c - 2\Delta z\, z_0 - \Delta z^2$$

$$z_0 = -\frac{C_s}{g}$$

$$\therefore \quad x_1^2 = \frac{2\Delta z\, C_s}{g} + 2\Delta z\, z_c - \Delta z^2$$

$$x_1^2 = \frac{A}{g} + B \qquad g = \frac{A}{x_1^2 - B}$$

$$A = 2\Delta z\, C_s$$
$$B = 2\Delta z\, z_c - \Delta z^2$$

CASE I :

$Z_c = 426$ Yds

$\Delta Z = 93$ Yds [DEPTH = 333 Yds]

$C_s = 1624$ Yds / SEC

$A = 2\Delta Z\, C_s = 2(93)(1624) = 302 \times 10^3$

$B = 2\Delta Z\, Z_c - \Delta Z^2$

$B = 2(93)(426) - (93)^2 = 72.5 \times 10^3$

$$\gamma_1^2 = \frac{302 \times 10^3}{g} + 72.5 \times 10^3$$

CASE II

$Z_c = 426$ Yds

$\Delta Z = 226$ Yds [DEPTH = 200 Yds]

$C_s = 1624$ Yds / SEC

$A = 2\Delta Z\, C_s = 2(226)(1624) = 735 \times 10^3$

$B = 2\Delta Z\, Z_c - \Delta Z^2 = 2(226)(426) - (226)^2 = 141 \times 10^3$

$$\gamma_1^2 = \frac{735 \times 10^3}{g} + 72.5 \times 10^3$$

FIGURE 1 SHOWS THE VELOCITY GRADIENT DISTRIBUTION FUNCTION BASED UPON THE NINE SAMPLES. FIGURE 2 SHOWS THE VELOCITY GRADIENT DENSITY FUNCTION PLOTTED FROM THE DISTRIBUTION FUNCTION. ALSO SHOWN ARE POINTS FOR A RAYLEIGH DENSITY FUNCTION IN y WHERE $y = g_0 - .016$. IT CAN BE SEEN THAT THE VELOCITY GRADIENT DENSITY APPROXIMATES THE RAYLEIGH DENSITY. OF PRIME IMPORTANCE IN NANOOSE ARE THE RANGES WHERE THE HORIZONTAL RAY FROM A PROJECTOR LOCATED AT A DEPTH OF 426 YdS, CROSSES THE 333 Yd DEPTH AND THE 200 Yd DEPTH.

$$p(x > x_1) = \int_{x_1}^{\infty} f(x)\, dx$$

$$= \int_{g_1}^{g(\infty)} \underline{f(g)\, dg} \quad \underline{u(g - .016)}$$

$$g_1 = \frac{A}{x_1^2 - B}$$

$$g(\infty) = 0$$

$$p(x > x_1) \quad \int_0^{\frac{A}{x_1^2-B}} f(g)\,dg \;\; u(g - .016) = \int_{.016}^{\frac{A}{x_1^2-B}} f(g)\,dg$$

let $y = g - .016$

$$p(x > x_1) = \int_0^{\frac{A}{x_1^2-B} - .016} \frac{y}{\alpha^2} \exp\left[-\frac{1}{2}\,\frac{y^2}{\alpha^2}\right] dy$$

$$= -\exp\left[-\frac{1}{2}\,\frac{y^2}{\alpha^2}\right] \Bigg|_0^{\frac{A}{x_1^2-B} - .016}$$

$$= 1 - \exp\left[-\frac{1}{2}\,\frac{\left(\frac{A}{x_1^2-B} - .016\right)^2}{\alpha^2}\right]$$

CASE I RECEIVER = 333 yds

$A = 302 \times 10^3$ $\qquad\qquad \alpha = .01$

$B = 72.5 \times 10^3$

x_1 (yds)	$p(x > x_1)$
2500	.9954
3000	.8340
3500	.332
4000	.016

CASE II RECEIVER = 200 yds

$A = 735 \times 10^3$
$B = 141 \times 10^3$

x_1 (yds)	$P(x > x_1)$
3500	.99995
4000	.99
4500	.90
5000	.59
6000	.044

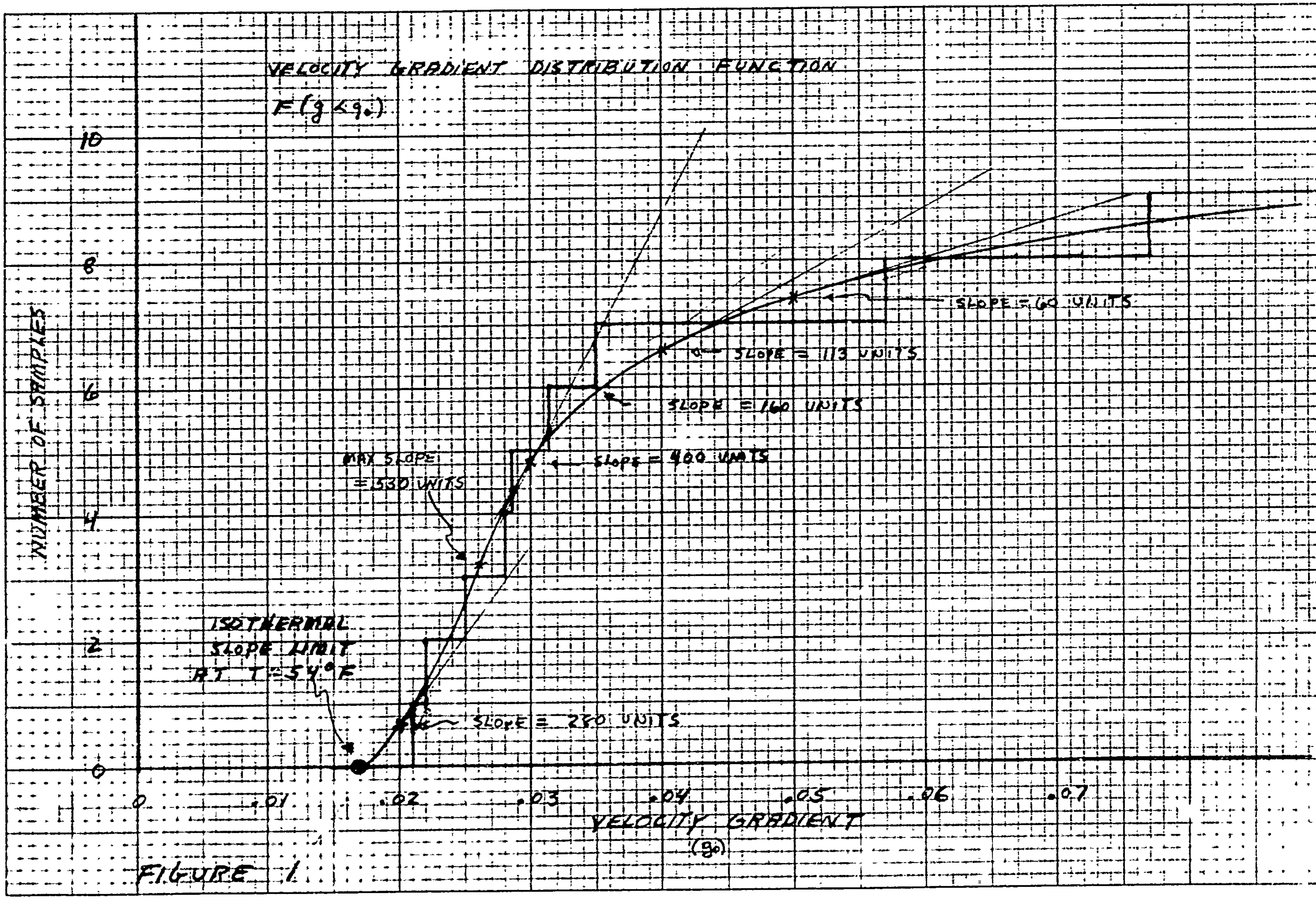

VELOCITY GRADIENT DISTRIBUTION FUNCTION
F(g<g₀)
NUMBER OF SAMPLES
VELOCITY GRADIENT
(g₀)
0
2
4
6
8
10
0
.01
.02
.03
.04
.05
.06
.07
SLOPE = 60 UNITS
SLOPE = 113 UNITS
SLOPE = 160 UNITS
SLOPE = 400 UNITS
MAX SLOPE = 530 UNITS
SLOPE = 280 UNITS
ISOTHERMAL SLOPE LIMIT AT T = 54°F

FIGURE 1

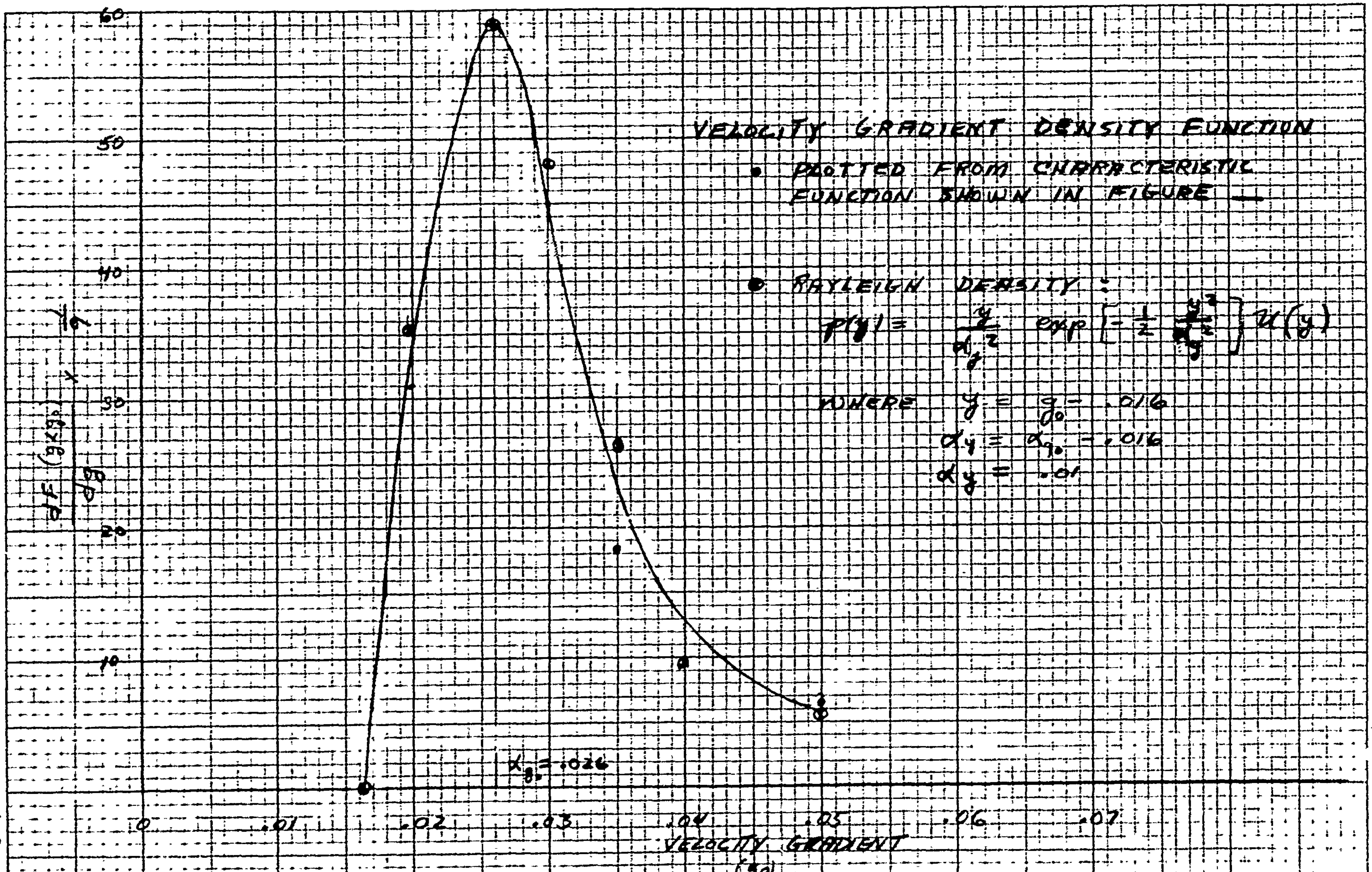

VELOCITY GRADIENT DENSITY FUNCTION
• PLOTTED FROM CHARACTERISTIC FUNCTION SHOWN IN FIGURE —
● RAYLEIGH DENSITY :
$p(y) = \frac{y}{\alpha_y^2} \exp\left[-\frac{1}{2}\frac{y^2}{\alpha_y^2}\right] u(y)$
WHERE $y = g_0 - .016$
$\alpha_y = \alpha_{g_0} - .016$
$\alpha_y = .01$
$\alpha_{g_0} = .026$
$\frac{dF(g_0)}{dg_0} \times \frac{1}{6}$
VELOCITY GRADIENT (g_0)
0
.01
.02
.03
.04
.05
.06
.07
10
20
30
40
50
60

FIGURE 2